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The Performance Index of Tidal Marsh Irrigation Area

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ABSTRACT

This research intends to build a performance index model in tidal marsh irrigation area due to the 5 pillars approaches of irrigation modernization. This research is conducted in the South Borneo Province where has wide enough swamp irrigation area that is managed by center government as well as province or regency or city government. The swamp area in the South Borneo Province based on the Ministry Rule of PUPR No. 14/PRT/M/2015 is about 238,122 ha due to the 583 units of swamp irrigation area that are managed by General Work Department (PU) and are spread in some regencies or cities in the South Borneo region. The methodology consists of planning, determining, and installing the location of water level measurement, to calibrate the measurement tool, to measure the water level by using the measurement tool, to analyze the parameters that are influenced the performance index by SEM-PLS, and to build the performance index by using GRG. The result shows that the performance index of tidal marsh irrigation area consists of 40 % physical, 16% crop productivity, 9% personal organization, 9% operation and maintenance, 8% documentation, and 18% farmers' association of water users (P3A). However, the physical, crop productivity, personal organization, operation and maintenance, documentation, and P3A has each formulation.

Keywords: Performance Index Model, Tidal Marsh Irrigation Area, Modernization Of Irrigation, Agriculture, SEM-PLS, GRG

INTRODUCTION

The tidal marsh areas that will be developed as agricultural area is necessary to adapt the condition and characteristic area so the agricultural yields can be optimal. The adapted conditions and characteristics to be addressed are as follows: the selected water system must be able to solve the available problem, and the adjustment of selected commodity in the effort to increase the function of tidal marsh area is necessary to attend the area hydro topography (Herawati et.al, 2010). The condition of hydro topography is an initial consideration to plan the water management in the tidal marsh area (Ngudiantoro et.al, 2010; Mulbah et.al, 2025). Based on the tidal marsh hydro topography, it is classified into flood types of A, B, C, and D; however, based on the effect of hydro topography, the highest concentration of Fe is mainly in the zone-I (downstream area) for type-A as well as type-B near the sea estuary (Mawardi et.al, 2020). The iron poisoning and soil acidity are the constraints of biophysical area that is frequently faced by the farmers on the LPRS agrosist (Koesrini, 2018).

The main problem that is faced in the paddy plantation in tidal marsh area is the condition of biophysical area (mainly water and area fertility problems), climate change, socio-economic conditions that are human resources (farmers), the limitation of infrastructures and facilities, and the policy that has not taking sides yet to the optimization of sub-optimal area utilization (Koesrini, 2017; Brata et.al, 2025). The tidal marsh area with sour sulfate has extreme chemical characteristic and fragile ecosystem, if it is developed as agricultural area will face some obstacles like the poisoning of aluminum (Al), iron (Fe), hydrogen sulfide (H_2S), and deficiency of phosphate. It generally has high aluminum (Al) solubility due to the high soil acidity and it can cause the Al solubility increases. However, the factors that can cause the Al poisoning are concentration of Al in soil solution, pH of soil, type of soil, and the availability of P soil. The high solubility of Al and Fe in soil solution can cause the binding P by Al and Fe to form Al-P and Fe-P that causes the availability of P nutrients for crop become decreasing which the deficiency of P can cause the obstruction of crop growth. The low value of pH causes the high solubility of Al, Fe, and Mn which then they become as poison for crop. If the value of pH is increasing until neutral or higher and it is followed with rainfall (Dheyab et.al, 2025; Maman et.al, 2022), so the number of ions will be decreasing in the soil solution that causes the decreasing of Fe and Mn for the certain crop (Alwi et.al, 2021). If the pH is maintained between 6 to 7, so the toxicity possibility of Al, Fe, and Mn can be prevented (7). According to Suntadi in Bakri et.al (2020), the layer depth of pyrite in the sulfate acid area is influential to the pH of soil, the getting shallower the depth from soil surface causes the getting lower the pH of soil (Othman et.al, 2020).

To increase the poisoning, it is needed the regulation of water level depth (TMA) and pH of water in the area that are in accordance with crop water consumption (Biro et.al, 2020) mainly paddy in the crop growth period, so there is obtained good harvest yield. Water regulation through one-way flow system besides can prevent and suppress the oxidation of pyrite, because the inundation makes the soil condition into reductive and washing/ flushing can decrease the accumulation of poisoned unsure (Subagio, 2019). The intermittent water regulation that is to be inundated and dried one weak intermittently can control the iron poisoning in the tidal marsh area (Alwi et.al, 2021; Anwar, 2017; Lamb et.al, 2025). In the Blango et.al (2019), from third irrigation treatments (AWD, ARS, and CFI) on the DS plantation, the water treatment of CFI has the highest crop productivity. It indicates how important to maintain water during the crop growth period. The intermittent water regulation (inundation and drying intermittently every week) gives positive influence to the soil reduction and oxidation condition that is to be able to suppress poisoned iron solubility, the growth of crop height, and number of rice's seedings are higher than continuously inundation of water regulation (Koesrini, 2018). Paddy needs water regulation between 10 cm until 30 cm under soil surface, however, paddy will be water deficit if water level depth is below 2 cm certain (7). To regulate groundwater level depth in the area block for supporting the agricultural system, can be controlled through the water level depth in tertiary channel (Mawardi et.al, 2020; Ngudiantoro et.al, 2010). However, the highest concentration of Fe2+ is in the 2-15 cm depth and then decreases on the bottom layer that contents fewer organic materials. So, to crop paddy in tidal marsh area, because the distribution of Fe concentration on the soil profile tends to decrease by the depth, there is suggested to use big size seed which the stem and root can reach the depth more than 10 cm. The research result of Yudianto et.al (2017) is carried out the inundation in the area until 20 cm over layer surface (top soil) for avoiding the risk of oxidated pyrite. The performance of an irrigation area is an indication to illustrate the irrigation system management. By knowing the performance index of irrigation infrastructures on the post development and rehabilitation, it is hoped can determine the life time of design, so it can determine what actions are needed to be carried out for maintaining the performance and in the end can estimate how much cost that is needed for maintaining the performance (Ahyadi et.al, 2018; Mulyadi, 2014). Evaluation of the performance index of irrigation network (IKSI) is needed to give an illustration of the available existing condition for determining the priority of allocating the program and activity budgeting (Asmelita et.al, 2024), so the implementation of program and activity have the justifiable basis. In the reformation of irrigation management that is to increase the performance of irrigation management for supporting the food and water resilience, the Ministry of General Work and Housing (PUPR) published a circular letter of the General Directorate of Water Resources No. 01/SE/D/2019 which the management of irrigation system must be oriented on the effective, efficient, and sustainable fulfillment at Level of Irrigation Service. However, the management of an irrigation must be carried out by attending 5 pillars that are the increasing of water supply reliability, facilities and infrastructures, irrigation management, management institution, and human resources which is known as Modernization of Irrigation. The tidal marsh characteristic that is less fertile is a main factor of the low land productivity (Useng, 2013) that is the low soil fertility due to the acid and pyrite soil characteristic (Arsyad, 2014). Besides the constraint of biophysical land, according to Alihamsyah et.al (2003), Subagio (2019), and Kariyasa (2017), the limitation of knowledge, skill, and ability of farmers in technology of plantation, the limitation of capital, infrastructure, and supporting institution like counseling, capital, as well as marketing, and the lack of young generations interest for plunging to the agricultural sector are also as the trigger factors of the production is still low in the tidal marsh irrigation areas (Taylor et.al, 2021). However, the utilization of tidal marsh area in supporting the increasing program of national food production can still be carried out because there are available various of technology innovations (Inounu et.al, 2017; Rowland et.al, 2024) like: 1) technology of water and soil management that consists of micro water system, land arrangement, improve, and fertilization; 2) new high-yielding varieties that are more adaptive and productive; and 3) agricultural tools and machines that is accordance with the typology of the land. Therefore, the assessment of the management performance of a tidal marsh irrigation is also needed to consider the special condition in the tidal marsh area and the utilization of agricultural technology innovation in the tidal marsh area management.

The success and sustainability of agricultural development in tidal marsh area through the technology application of land management and the selection of accurate commodity is needed to be supported by the ability of human resources, facilities and infrastructures, and effective and efficient institution. Generally, the development of tidal marsh area in the future, must fulfill 3 conditionals as follows: technically is easy to be implemented and can be accepted by the society, economically is feasible and profitable, and does not damage the environment so the natural resources are just well preserved so the agricultural development can be sustainable (Alihamsyah et.al, 2003). To implement this, remembering that there are some constraints that are faced in the utilization, so it is needed research to know the influence of water level depth and pH of water in the tidal marsh area to the paddy productivity.

MATERIALS AND METHODS

Research Location

The research location is conducted in the South Borneo Province where has wide enough swamp irrigation area that is managed by center government as well as province or regency or city government. The swamp area in the South Borneo Province based on the Ministry Rule of PUPR No. 14/PRT/M/2015 (Kementerian PUPR, 2015) is about 238,122 ha due to the 583 units of swamp irrigation area that are managed by General Work Department (PU) and are spread in some regencies or cities in the South Borneo region.

The Barito Kuala Regency is selected as the research location, remembering that the area there is still affected by ebb and flow (tides). This research location is presented as in Figure 1.

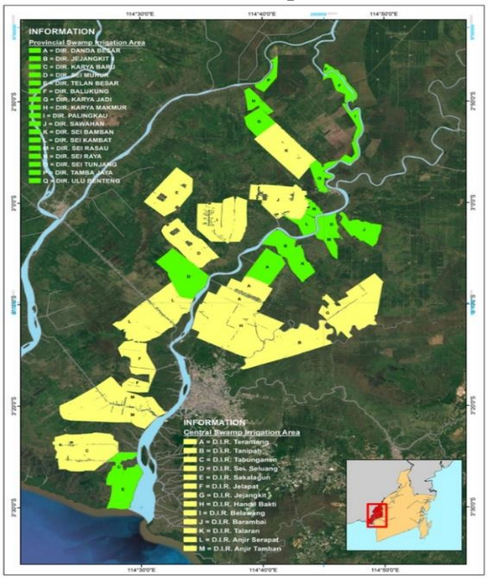

Figure 1. Location Spread of Tides Irrigation Area in Barito Kuala Regency

Tidal Marsh Irrigation Area

Tidal marsh is a landform that has relatively plain topography or sunken with bad drainage condition and naturally is flooded along year or during certain period and long enough (one season). Marsh can be meant as flooded area that is naturally continuously or seasonal due to the natural drainage that is hampered and physically, chemically, biologically has specific characteristics (Craft, 2023; Waclimad, 2012; Yudianto et.al, 2017). The physical characteristic of marsh generally is sunken ground conditions with relatively plain topography, the chemical characteristic generally is low degree of water acidity and or as inorganic soil or contains pyrite, and the biological characteristic generally has the specific flora and fauna.

According to Wijaya and Adhi (1986), the tidal marsh area is very influential by ocean tide that periodically is experiencing a tidal surge, so the tidal marsh area is said as an area that gets the effect of tides or rivers surrounding it. In rainy season, the areas are flooded until 1 m over the soil surface and in dry season, the groundwater surface even reaches more than 50 cm under soil surface. According to the coordination team of P2NPLRB (National Planning Formulation of Sustainable Swamp Area Management), an area can be mentioned as swamp area if meets 4 elements as follows: a). Saturated with water until flooded continuously or periodically and causes anaerobic situation.; b) Sloping topography, plain until sunken; c) Mineral sediment (due to erosion that is carried by the stream) and or peatland (due to the pile of remaining local vegetation); and d) Overgrown with vegetation naturally (Ghozali, 2011).

The tidal marsh area is in the zone/ region surrounding coast that is marked by the direct influence if run-off from the ebb and flow of the sea water or only influential on the groundwater surface. Most of soil types on the tidal marsh area are from peatland and acid sulphate soil. The zone classification of tidal marsh along watershed is presented in Figure 2.

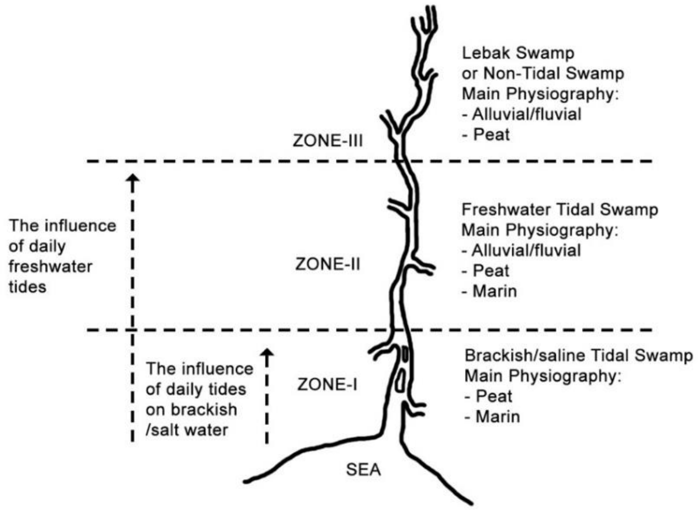

Figure 2. Zone Classification of Tidal Marsh along Watershed

According to Wijaya and Adhi (1986), the tidal marsh area can be classified into 4 main typologies based on the type and level of the land physics-chemical constraints as follows: 1) Potential land (deep pyrite), 2) acid-sulphate land (potential and actual), 3) peatland (peaty and organic peat), and 4) not characterized land. This typology is used for making easy the management of tidal marsh.

RESULTS AND DISCUSSION

This research focusses on the model development of structural equation that can be used for measuring the actual performance of tidal marsh irrigation area which is based on the 5 pillars of irrigation modernization. The research is started by collecting the documents of the model performance assessment of PAKSI DIR in South Borneo Province-Indonesia that is in the tidal marsh irrigation area as the authority of center and province that has been carried out the performance assessment. Performance assessment data of tidal marsh irrigation area due to the PAKSI method generally in South Borneo Province are presented in Table 1.

Table 1. Performance Assessment of Tidal Marsh Irrigation Area Due to the PAKSI Model

No	Irrigation Area Name	Performance Index	Production	Service Level	Performance Index	Production	Service Level	Performance Index	Production	Service Level
		2020			2021			2022		
1	D.I.R. Anjir Tamban	45.81	8.00	Bad	54.26	3.20	Bad	26.54	6.13	Bad
2	D.I.R. Anjir Serapat	45.11	4.00	Bad	52.63	5.00	Bad	55.82	6.13	Bad
3	D.I.R Tabungannen	62.00	5.00	Less	44.71	3.00	Bad	39.45	6.13	Bad
4	D.I.R. Belanti	55.50	2.00	Less	60.35	3.00	Less	28.50	6.13	Bad
5	D.I.R Berambai	54.33	4.00	Bad	70.06	1.05	Good	77.62	6.13	Good
6	D.I.R Belawang	41.82	4.00	Bad	66.84	3.00	Less	61.03	6.13	Less
7	D.I.R Sakalagun	56.85	1.50	Less	50.84	1.50	Bad	52.90	6.13	Bad

8	D.I.R Terantang	70.45	5.00	Good	68.21	5.00	Less	58.73	3.75	Bad
10	D.I.R Alalak Padang	0	0	-	48.69	3.88	Bad	48.69	3.88	Bad
11	D.I.R Antasan Kyai	0	0	-	39.17	2.50	Bad	39.17	2.50	Bad
12	D.I.R Antasan Tanipah	0	0	-	44.30	2.50	Bad	44.30	2.50	Bad
15	D.I.R Danda Besar	0	0	-	48.39	4.00	Bad	48.39	4.00	Bad
16	D.I.R Jejangkit Ii	0	0	-	56.95	4.00	Less	56.95	4.00	Less
17	D.I.R Sei Bamban	0	0	-	58.79	2.50	Less	58.79	2.50	Less
18	D.I.R Sei Tunjang	0	0	-	60.21	4.00	Less	60.21	4.00	Less
19	D.I.R Sei Rasau	0	0	-	53.03	4.00	Bad	53.03	4.00	Bad
20	D.I.R Sei Raya	0	0	-	61.39	4.00	Less	61.39	4.00	Less
21	D.I.R Sawahan	0	0	-	50.89	4.00	Bad	50.89	4.00	Bad
22	D.I.R Sei Kambat	0	0	-	59.18	2.50	Less	59.18	2.50	Less
23	D.I.R Karya Jadi	0	0	-	57.90	2.50	Less	57.90	2.50	Less
24	D.I.R Karya Makmur	0	0	-	62.08	2.50	Less	62.08	2.50	Less
25	D.I.R Tamba Jaya	0	0	-	55.17	2.50	Less	55.17	2.50	Less
26	D.I.R Karya Baru	0	0	-	51.26	2.50	Bad	51.26	2.50	Bad
27	D.I.R Telan Besar	0	0	-	46.15	2.50	Bad	46.15	2.50	Bad
28	D.I.R Balukung	0	0	-	50.50	2.00	Bad	50.50	2.00	Bad
29	D.I.R Palingkau	0	0	-	59.23	3.50	Less	59.23	3.50	Less
30	D.I.R Sei Muhur	0	0	-	46.12	4.00	Bad	46.12	4.00	Bad
31	D.I.R Ulu Benteng	0	0	-	58.05	4.00	Less	58.05	4.00	Less

Based on the recommendation from the document, if it is reviewed from the value of performance condition and classification, the criteria that is used are as follows: very good performance (80-100%); good performance ($70 < X \leq 80$ %); less performance ($55 < X \leq 70$ %); and bad performance (≤ 55 %). Therefore, the data above shows that 93.6% of 70 unit of IKSI data are in the less until bad condition; only 6.4% is in the good performance condition. The recommendation of asset handling in tidal marsh irrigation network is presented in Table 2.

Table 2. Recommendation of Aset Handling in Tidal Marsh Irrigation Network

No.	Condition of network asset	Weight (%)	Function of network asset	Weight (%)	Handling recommendation
1.	Very good	90 - 100	Very good	90 - 100	Routine maintenance
2.	Good	80 ≤ 90	Good	80 ≤ 90	Periodical maintenance (Maintained)
3.	Moderate	60 ≤ 80	Moderate	60 ≤ 80	Periodical maintenance (Improved)

4.	Bad	1 ≤ 60	Bad	1 ≤ 60	Change/ rehabilitation
5.	Not working	0	Not working	0	Review design/rehabilitation

Performance Index Model

Indonesian Government target as World Food Basket (LPD) on 2015, however, the big challenge is blocking as the area conservation, population growth, and extreme climate change. One of the potential solutions is the utilization of swamp land that can increase the food production mainly rice. For instance, by increasing the productivity of 1.15 million ha swamp area into IP 200, it can produce 3,5-million-ton grain per-year. The even wider utilization as hunchback (bongkor) swamp of 4.1 million ha is potential to produce 16.52-million-ton grain, it is equivalent with 9.9-ton rice that can be make surplus rice for Indonesia.

Parameter on the Performance Index Assessment of Tidal Marsh Irrigation Network

This research is conducted in 14 locations with 42 observation points that are on the Left Channel Ray 9, Left Channel Ray 15, Left Channel Ray 21, Left Channel Ray 27, Left Channel Ray 33, Left Channel Ray 39, Left Channel Ray 46, Right Channel Ray 10, Right Channel Ray 21, Right Channel Ray 27, Right Channel Ray 33, Right Channel Ray 39, Right Channel Ray 46.

The survey data are carried out for obtaining the criteria value of each variable and index as follows: criteria values of Physical Infrastructure Aspect (APF), Crop Productivity Aspect (APD), Operation and Maintenance Aspect (AOL), Organization and Personnel Aspect (AOR), Documentation Aspect (ADO), and Farmers' Association for Water Users/ P3A (APA). All of them will be carried out the assessment that is classified into 5 criteria that are very good, good, moderate, bad, and non-functional. Table 3 presents the assessment score of PAKSI assessment technical guidance.

Table 3. Assessment Score of PAKSI Technical Guidance

Category	Score	Percentage
Very good	1	90-100
Good	2	80-<90
Moderate	3	60-<80
Bad	4	1-<60
Non/ not working	5	0

From the assessment category that has been available, when it is carried out the running by using application of Smart-PLS, there is produced the homogenic result. It is due to the part of observed data have the same value, there is no value difference from every indicator. To solve the problem, there is carried out the modification of data by detailing the assessment parameter of tidal marsh performance from the PAKSI technical guidance and the score of research assessment is presented in Table 4.

Table 4. Score of Research Assessment

Category	Score	Percentage
Very good	1	100
Very good-1	1.3	96
Very good-1	1.6	92
Good	2	88
Good-1	2.3	84
Good-2	2.6	80
Moderate	3	76
Moderate-1	3.2	72
Moderate-2	3.4	68
Moderate-3	3.6	64
Moderate-4	3.8	60
Bad	4	50
Bad-1	4.2	40

Bad-2	4.4	30
Bad-3	4.6	20
Bad-4	4.8	10
Non	5	0

Based on the validity evaluation of the research variables, the first iteration shows that all of indicators have the factor loading more than the criteria which is used in this research that is 0.5. The next step is carried out the analysis of reliability test which intends to know the reliability of data. The value will be categorized reliable if the value is more than 0.8, however, if the reliability value does not reach 0.8, so the value can be categorized reliable enough if the value is between 0.6 until 0.8 ($0.8 > \varrho c > 0.6$). The value of Average Variance Extracted (AVE) is said reliable if it indicates over than 0.50. From the reliability test, there are obtained that all of the results are reliable. Then it is continued with the hypothesis test from the structural model, significance level of path coefficient that is obtained from t calculation and the value that shows the standardized path coefficient as the basic test with the critical boundary is 1.699 based on the t calculation (5%) with 14 research samples (respondents).

The Relation between Aspect Variable, Indicator, and Sub-indicator

The performance index model of tidal marsh irrigation system is the approach of performance index that consists of 6 variables. The sub-indicators regarding to the classification from the indicators, and to be arranged from sub-indicators that are determined.

1. Physical Infrastructure Aspect (APF)

The Physical Infrastructure Aspect (APF) is arranged as follows:
$IK_{\text{Physical Infrastructure}} = a_1.\ APF_1 + a_2.\ APF_2 + a_3.\ APF_3 + a_4.\ APF_4 + a_5.\ APF_5$
With:
$APF_1 = a_{1.1}.APF_{1.1} + a_{1.2}.APF_{1.2} + a_{1.3}.APF_{1.3}$ (Condition of channel)
$APF_2 = a_{2.1}.APF_{2.1} + a_{2.2}.APF_{2.2} + a_{2.3}.APF_{2.3} + a_{2.4}.APF_{2.4}$ (Gate Structure)
$APF_3 = a_{3.1}.APF_{3.1}$ (Supporting Structure)
$APF_4 = a_{4.1}.APF_{4.1} + a_{4.2}.APF_{4.2} + a_{4.3}.APF_{4.3} + a_{4.4}.APF_{4.4} + a_{4.5}.APF_{4.5}$ (Availability of Measurement Tool)
$APF_5 = a_{5.1}.APF_{5.1}$ (Production Road); a_1= weight of channel condition; a_2= weight of gate structure; a_3= weight of supporting structure; a_4= weight of measurement tool availability; a_5= weight of production road; $a_{1.1}$= weight of embankment; $a_{1.2}$= weight of berm; $a_{1.3}$= weight of wet cross section; $a_{2.1}$= weight of foundation floor; $a_{2.2}$= weight of wall; $a_{2.3}$= weight of wing; $a_{2.4}$= weight of leaf doors; $a_{3.1}$= weight of trash filter, hand rail, culvert etc.; $a_{4.1}$= weight of peilscal/AWLR; $a_{4.2}$= weight of rainfall measurement tool; $a_{4.3}$= weight of pH meter (water); $a_{4.4}$= weight of pH meter (soil); $a_{4.5}$ = weight of piezometer
The constraints:

- $1 \leq IK_{\text{physical aspect}} \leq 5$
- $APF_1 + APF_2 + APF_3 + APF_4 + APF_5 = 1$
- $APF_{1.1} + APF_{1.2} + APF_{1.3} + APF_{2.1} + APF_{2.2} + APF_{2.3} + APF_{2.4} + APF_{3.1} + APF_{4.1} + APF_{4.2} + APF_{4.3} + APF_{4.4} + APF_{4.5} + APF_{5.1} = 1$

$c_{1.1}$= weight of the availability and skill of the technical staff
$c_{2.1}$= weight of the availability and skill of block head
The constraint:

- $I \leq IK_{\text{organization -personnel}}$ aspect ≤ 5
- $AOR_1 + AOR_2 = 1$
- $AOR_{1.1} + AOR_{2.1} = 1$

2. Crop Productivity Aspect (APD)

The Crop Productivity Aspect (APD) is arranged as follows:
$IK_{\text{Crop Productivity}} = b_1.\ APD_1 + b_2.\ APD_2 + b_3.\ APD_3$, with:
$APD_1 = b_{1.1}.\ APD_{1.1} + b_{1.2}.\ APD_{1.2} + b_{1.3}.\ APD_{1.3}$ (Crop Productivity)
$APD_2 = b_{2.1}.\ APD_{2.1} + b_{2.2}.\ APD_{2.2}$ (Water Level Depth)
$APD_3 = b_{3.1}.\ APD_{3.1} + b_{3.2}.\ APD_{3.2}$ (Condition of pH)
b_1 = weight of crop productivity; b_2 = weight of water level depth; b_3 = weight of pH; $b_{1.1}$ = weight of real crop area; $b_{1.2}$ = weight of paddy productivity; $b_{1.3}$ = weight of horticulture productivity; $b_{2.1}$ = weight of channel (water level depth); $b_{2.2}$ = weight of agriculture area (water level depth); $b_{3.1}$ = weight of channel (pH); $b_{3.2}$ = weight of agriculture area (pH)

The constraints:

- $1 \leq IK_{\text{crop productivity aspect}} \leq 5$
- $APD_1 + APD_2 + APD_3 = 1$
- $APD_{1.1} + APD_{1.2} + APD_{1.3} + APD_{2.1} + APD_{2.2} + APD_{3.1} + APD_{3.2} = 1$

3. Organization and Personnel Aspect (AOR)

The Organization and Personnel Aspect (AOR) is arranged as follows:
$IK_{\text{Organization-Personnel}} = c_1.\ AOR_1 + c_2.\ AOR_2$
With:
$AOR_1 = c_{1.1}.\ AOR_{1.1}$ (Technical Staff)
$AOR_2 = c_{2.1}.\ AOR_{2.1}$ (Head of Block)
c_1 = weight of technical staff; c_2 = weight of block head; $c_{1.1}$ = weight of the availability and skill of technical staff; $c_{2.1}$ = weight of the availability and skill of block head
The constraints:

- $1 \leq IK_{\text{Organization-Personnel Aspect}} \leq 5$
- $AOR_1 + AOR_2 = 1$
- $AOR_{1.1} + AOR_{2.1} = 1$

4. Aspect of Operation and Maintenance (AOL)

The Aspect of Operation and Maintenance (AOL) is arranged as follows:
$IK_{\text{Operation and Maintenance}} = d_1.\ AOL_1 + d_2.\ AOL_2$
With:
$AOL_1 = d_{1.1}.\ AOL_{1.1} + d_{1.2}.\ AOL_{1.2}$ (Cleaning)
$AOL_2 = d_{2.1}.\ AOL_{2.1}$ (Supporting Equipment)
d_1= weight of cleaning; d_2 = weight of supporting equipment; $d_{1.1}$ = weight of channel; $d_{1.2}$ = weight of berm; $d_{2.1}$= weight of supporting equipment condition
The constraints:

- $1 \leq IK_{\text{Operation and Maintenance}} \leq 5$
- $AOL_1 + AOL_2 = 1$
- $AOL_{1.1} + AOL_{1.2} + AOL_{2.1} = 1$

5. Aspect of Documentation (ADO)

The Documentation Aspect (ADO) is arranged as follows:
$IK_{\text{Documentation}} = e_1.\ ADO_1 + e_2.\ ADO_2$
With:
$ADO_1 = e_{1.1}.\ ADO_{1.1}$ (Data Book of Tertiary Block)
$ADO_2 = e_{2.1}.\ ADO_{2.1}$ (Map and Figure)
e_1= weight of data book of the tertiary block; e_2 = weight of map and figure; $e_{1.1}$ = weight of the data book of tertiary block' $e_{2.1}$= weight of map and figure
The constraints:

- $1 \leq IK_{\text{Documentation Aspect}} \leq 5$
- $ADO_1 + ADO_2 = 1$
- $ADO_{1.1} + ADO_{2.1} = 1$

6. Aspect of P3A

The P3A Aspect (ADO) is arranged as follows
$IK_{P3A} = f_1.\ APA_1 + f_2.\ APA_2 + f_3.\ APA_3 + f_4.\ APA_4 + f_5.\ APA_5 + f_6.\ APA_6 + f_7.\ APA_7 + f_8.\ APA_8$
With:
$APA_1 = f_{1.1}.\ APA_{1.1}$ (Legal Institution Status); $APA_2 = f_{2.1}.\ APA_{2.1}$ (Institution Condition); $APA_3 = f_{3.1}.\ APA_{3.1}$ (Meeting Activity); $APA_4 = f_{4.1}.\ APA_{4.1}$ (Survey Activity); $APA_5 = f_{5.1}.\ APA_{5.1}$ (Improvement Participation); $APA_6 = f_{6.1}.\ APA_{6.1}$ (Dues of OP); $APA_7 = f_{7.1}.\ APA_{7.1}$ (Communication with institution); $APA_8 = f_{8.1}.\ APA_{8.1}$ (Functional Ability); f_1 = weight of Legal Institution Status; f_2 = weight of institution condition; f_3= weight of meeting activity; f_4 = weight of survey activity; f_5 = weight of improvement participation; f_6 = weight of OP dues; f_7 = weight of coordination ability; f_8 = weight of communication with agency; $f_{1.1}$ = weight of legal agency status; $f_{2.1}$= weight of institution condition; $f_{3.1}$= weight of meetings activities; $f_{4.1}$= weight of survey/ network routing; $f_{5.1}$= weight of participation in network improvement and handling; $f_{6.1}$= weight of OP Dues for tertiary; $f_{7.1}$= weight of

functional ability and coordination in cropping pattern plan; $f_{8.1}$= weight of communication with the manager institution of main irrigation network

The constraints:

- $1 \leq IK_{\text{Aspect of P3A}} \leq 5$
- $APA_1 + APA_2 + APA_3 + APA_4 + APA_5 + APA_6 + APA_7 + APA_8 = 1$
- $APA_{1.1} + APA_{2.1} + APA_{3.1} + APA_{4.1} + APA_{5.1} + APA_{6.1} + APA_{7.1} + APA_{8.1} = 1$

The performance index of tidal marsh irrigation system consists of six aspects that are Physical Infrastructure Aspect (APF), Crop Productivity Aspect (APD), Organization and Personnel Aspect (AOR), Operation and Maintenance Aspect (AOL), Documentation Aspect (ADO), and Farmers' Association for Water Users/ P3A (APA). The influence size of each variable, indicator, and sub-indicator are illustrated from each coefficient.

After being carried out the 2 steps analysis through SEM with Smart-PLS and GRG method by using Microsoft Excel Solver, so the formulation of new performance index that is named as IK_{MDR} is as follows:

$$IK_{MDR} = 0.396\ IK_{\text{Physic}} + 0.165\ IK_{\text{Crop production}} + 0.094\ IK_{\text{Organization-personnel}} + 0.136\ IK_{\text{Operation-maintenance}} + 0.084\ IK_{\text{Documentation}} + 0.125\ IK_{\text{P3A}}$$

$$IK_{\text{physical-aspect}} = 0.262\ APF_1 + 0.259\ APF_2 + 0.086\ APF_3 + 0.324\ APF_4 + 0.069\ APF_5$$

$$IK_{\text{crop-production-aspect}} = 0.455\ APD_1 + 0.273\ APD_2 + 0.272\ APD_3$$

$$IK_{\text{personnel-organization aspect}} = 0.500\ AOR_1 + 0.500\ AOR_2$$

$$IK_{\text{operation-maintenance-aspect}} = 0.669\ AOL_1 + 0.331\ AOL_2$$

$$IK_{\text{documentation-aspect}} = 0.488\ ADO_1 + 0.512\ ADO_2$$

$$IK_{\text{P3A-aspect}} = 0.114\ APA_1 + 0.114\ APA_2 + 0.141\ APA_3 + 0.130\ APA_4 + 0.118\ APA_5 + 0.108\ APA_6 + 0.157\ APA_7 + 0.118\ APA_8$$

Based on the performance index of tidal marsh irrigation system above, it shows that the physical infrastructure aspect determines the performance of tidal marsh irrigation weight, the biggest weight that is 33.6%. It is due to the physical infrastructure aspect is a most important aspect in the tidal marsh irrigation system, so the effort to maintain in order to the tidal marsh irrigation system is functioned as it should be, must be determined the physical infrastructure formerly. This model is more representative to be used in the research of the performance index of tidal marsh irrigation area because the parameters have represented the whole components of tidal marsh irrigation system that have been built and the analysis uses the formulation model which is more suitable with the field condition as follows:

$$IK_{MDR} = 0.396\ IK_{\text{Physic}} + 0.165\ IK_{\text{Crop-production}} + 0.094\ IK_{\text{Organization-personnel}} + 0.136\ IK_{\text{Operation-maintenance}} + 0.084\ IK_{\text{Documentation}} + 0.125\ IK_{\text{P3A}}$$

This result is different with the technical guidance which the influence percentage of each to the aspect of tidal marsh irrigation system has the different weight. The weight difference of every aspect can be seen in Table 5.

Table 5. Weight Difference of Every Aspect in Tidal Marsh Irrigation

Variable	Technical Guidance	Performance Index Model (IK_{MDR})
Physical infrastructure	45%	39,6 %
Crop productivity	15%	16,5 %
Personnel organization	10%	9,4 %
Operation and Maintenance	15%	13,6 %
Documentation	5%	8,4 %
Farmers' Association of Water Users (P3A)	10%	12,5 %

Calibration

Calibration is carried out by testing the index result through the analysis with the field index value. The difference of them shows the value of relative error. If the value is not bigger than the error level that is determined, so the model can be accepted due to the fulfillment to the calibration condition that is not more than the error that is determined. The calculation of calibration is shown in Table 6 and Figure 3.

Table 6. Calibration of the Performance Index Model of Tidal Marsh Irrigation

Tidal Marsh Irrigation	IKEK calculation	IKEK field	Δ	Relative error
1	3.321376579	2.5	0.82137658	0.674659484
2	2.727291754	2.5	0.22729175	0.051661541
3	2.725461914	2.5	0.22546191	0.050833075

4	2.688851973	2.5	0.18885197	0.035665068
5	3.271312333	2.5	0.77131233	0.594922716
6	3.103857935	2.5	0.60385793	0.364644406
7	3.441030845	2.5	0.94103084	0.88553905
8	2.888905786	2.5	0.38890579	0.151247711
9	3.215476339	2.5	0.71547634	0.511906391
10	2.67660018	2.5	0.17660018	0.031187623
11	3.677679337	2.5	1.17767934	1.38692862
12	3.808267819	2.5	1.30826782	1.711564686
13	3.768229039	2.5	1.26822904	1.608404895
14	3.540140541	2.5	1.04014054	1.081892346

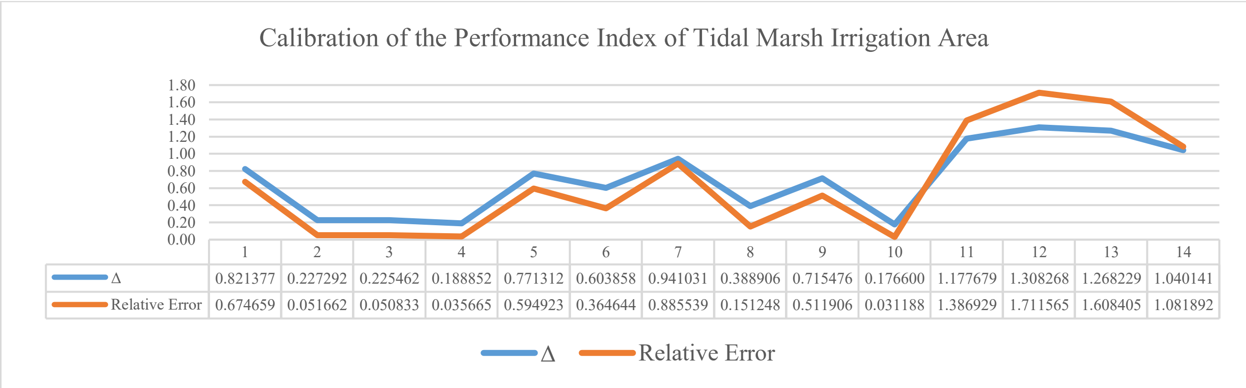

Figure 3 Calibration Curve of the Performance Index Model of Tidal Marsh Irrigation

From the table above, it can be concluded that the biggest error is on the swamp water irrigation No. 12 that is 1.7%, it means that it is more than the allowed error that is 10%. Meanwhile, the smallest error on the swamp water irrigation is No. 10 with the error of 0.031187623%.

Validation

Two ways t-test is used for validating the analysis of the performance index of tidal marsh irrigation system by comparing the calculation of t-value and t-table, so it is obtained the value as point in the distribution curve. The value will attend whether or not there is influence between variables (May, 2025). Calculation of t-test as the validation process of the performance index of tidal marsh irrigation system is presented in Table 7 and Figure 4.

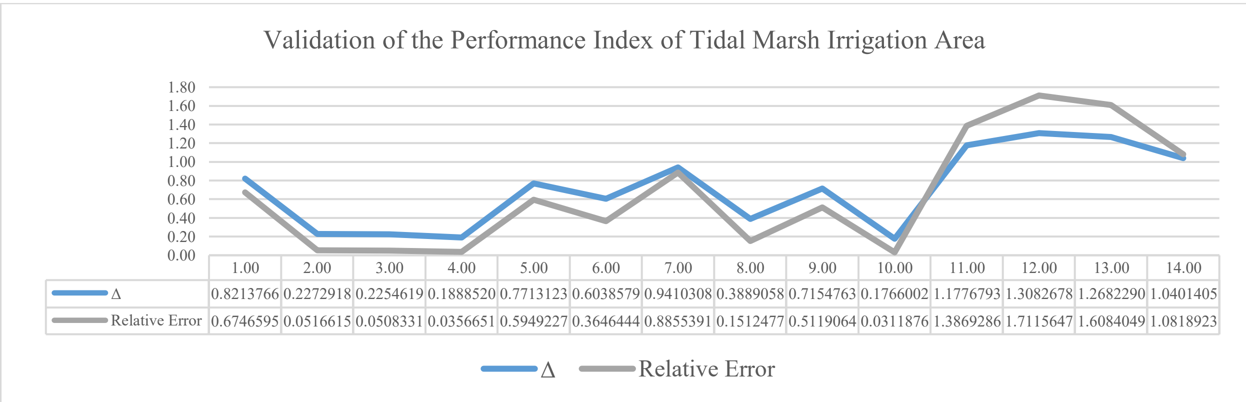

Figure 4 Validation Curve of the Performance Index Model of Tidal Marsh Irrigation

Table 7. Validation of the Performance Index Model of Tidal Marsh Irrigation

Tidal Marsh Irrigation	IKEK calculation	IKEK field	Δ	Relative error
1	3.321376579	2.5	0.82137658	0.674659484
2	2.727291754	2.5	0.22729175	0.051661541
3	2.725461914	2.5	0.22546191	0.050833075
4	2.688851973	2.5	0.18885197	0.035665068
5	3.271312333	2.5	0.77131233	0.594922716

6	3.103857935	2.5	0.60385793	0.364644406
7	3.441030845	2.5	0.94103084	0.88553905
8	2.888905786	2.5	0.38890579	0.151247711
9	3.215476339	2.5	0.71547634	0.511906391
10	2.67660018	2.5	0.17660018	0.031187623
11	3.677679337	2.5	1.17767934	1.38692862
12	3.808267819	2.5	1.30826782	1.711564686
13	3.768229039	2.5	1.26822904	1.608404895
14	3.540140541	2.5	1.04014054	1.081892346
Sum	44.85448237	35	9.85448237	9.141057613
χ	3.203891598		S^2	8.44913789
Average IKEK field	2.5		S	2.90674008
t table	1,34		t calculation	-0.242158425
σ	0.808042503		df	13
α table	0.1		α	0.05
Average Relative Error	0.652932687		Conclusion	t calculation < t table

CONCLUSION

This research intends to build a performance index model in tidal marsh irrigation area due to the 5 pillars approaches of irrigation modernization. This research is conducted in the South Borneo Province where has wide enough swamp irrigation area that is managed by center government as well as province or regency or city government. The swamp area in the South Borneo Province based on the Ministry Rule of PUPR No. 14/PRT/M/2015 is about 238,122 ha due to the 583 units of swamp irrigation area that are managed by General Work Department (PU) and are spread in some regencies or cities in the South Borneo region. The performance index model has 5 aspects that are physical infrastructure, crop productivity, personal organization, operation and maintenance, documentation, and P3A. The result shows that the performance index of tidal marsh irrigation area consists of 33.6 % physical, 16.5 % crop productivity, 9.4 % personal organization, 13.6 % operation and maintenance, 8.4 % documentation, and 18.5 % farmers' association of water users (P3A). However, the physical, crop productivity, personal organization, operation and maintenance, documentation, and P3A has each formulation

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