Efficiency of Smart Sluice Gate in Agricultural Water Distribution on Paddy (Oryza sativa L.)

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Abstract. The development of irrigation sluice gate is to optimize the use of water in agriculture, the development is carried out on a laboratory scale in the hydraulics and environment laboratory, then the implementation was located at PIAT UGM in block A covering an area of 6.93 ha, Kali Tirto Village. The objective of this research is investigate the efficiency of smart sluices with manual sluices using the Bernoulli equation. Based on the analysis, the efficiency in manual sluice openings with 10 variations obtained an average of 49%, while the smart sluice openings with a 5 cm open scenario, variations in gate openings can be carried out continuously, the average result of the smart sluice efficiency analysis is 72%, so the smart sluice has a greater efficiency value than the manual sluice gate

1. Introduction

Climate change predictions assume that most regions of the Indonesian Archipelago will suffer from a gradual decrease in water availability due to temperature increase and rainfall changes [1]. According to piece in manez [2] Although the country is expected to experience 2–3% more rainfall, there will be fewer rainy days per year and an increase in extreme rain events. This will significantly increase the risk of droughts and flash floods. In the case of flash floods, the relative amount of water that can be re-absorbed into the groundwater decreases severely.

The optimal and sustainable land use will have a significant impact on improving the country's economy and society. On this basis, the Government of Indonesia through the Ministry of Agrarian Affwaters and Spatial Planning [3] issued a regulation on the determination of agricultural land as support for achieving national food security.

The application of Artificial Intelligence (AI) intelligent systems to agriculture will generate extraordinary digital innovations and have several advantages, such as increased risk, environmental impact and inspire work. Smart systems in agriculture have been applied to various aspects, from seeding and planting to harvesting and post-harvest, from spraying to livestock management, and so on [4]. One of which the smart sluice system is designed to control and monitor the activity of irrigation channels such as, water flow, water temperature, water level, rain detection and an automation system to open and close the dam sluice. It is expecting that the water supply from the irrigation canal can be more optimal as well. lighten human work because with an intelligent irrigation system, activities can be carried out from a good distance...
using a smartphone, personal computer, or laptop, projection of Indonesian water availability shown in Table 1.

Table 1. Projection of Indonesian Water Availability [5]

| Years | Sumatera | Jawa | Bali | Kalimantan | Sulawesi | Maluku | Papua |
|-------|----------|------|------|------------|----------|--------|-------|
| 2000  | 12371.06 | 838.55 | 2411.12 | 61838.35 | 13659.40 | 40182.60 | 236139.96 |
| 2005  | 11482.08 | 777.08 | 2275.88 | 53546.24 | 11863.03 | 35398.52 | 206023.46 |
| 2010  | 10653.77 | 724.74 | 2149.88 | 49111.95 | 11053.59 | 33230.48 | 192382.93 |
| 2015  | 9886.60  | 676.40 | 2031.40 | 45754.75 | 10316.67 | 31194.01 | 179889.10 |
| 2020  | 9195.15  | 630.26 | 1920.31 | 43412.35 | 10175.85 | 29011.85 | 177474.05 |
| 2021  | 8931.01  | 621.26 | 1898.15 | 41711.95 | 9863.59 | 27451.80 | 175090.31 |
| 2022  | 8802.40  | 603.62 | 1877.53 | 40111.95 | 9573.14 | 25879.94 | 172732.30 |
| 2023  | 8675.48  | 595.08 | 1856.97 | 38543.75 | 9293.74 | 24350.18 | 170430.09 |
| 2024  | 8550.12  | 586.52 | 1836.40 | 37050.75 | 9023.34 | 22929.42 | 168132.25 |
| 2035  | 7393.86  | 509.97 | 1619.98 | 35595.86 | 8364.89 | 21515.61 | 146992.25 |
| 2040  | 6875.53  | 476.62 | 1526.69 | 34079.64 | 7808.14 | 20479.94 | 137474.19 |
| 2045  | 6392.18  | 445.82 | 1443.74 | 32741.38 | 7293.24 | 22550.18 | 128568.84 |

No stress : >1700  
Stress : 1000 – 1700  
Scarcity : 500 – 1000  
Absolute scarcity : <500  

Based on the Bappenas on KLHS RP JMN [5], the archipelago water availability ranks the lowest investigated to other islands, The Java islands was projected to experience absolute scarcity investigated to other islands, Overall, there has been a decrease in the number of water availability in the islands of Sumatra, Java, Bali, Kalimantan, Sulawesi, Maluku and Papua. So there was a need for innovation in conserving water and optimizing water use, one of which was a smart sluice gate so that water was not wasted excessively and tends to be in vain, Therefore this research was conducted to investigate manual/manual sluice gate with smart system gearbox sluice gate using a microcontroller combined with sensors, this article was a preliminary study conducting as a first step to conduct deeper research.

Research and development of sluice gate are very necessary to optimize the use of irrigation water, therefore the problems that can be drawn from this research are manual sluice gate are very often used without knowing the efficiency of the tool with other constraints such as delays in closing the sluice gate during floods, excessive water use in agricultural irrigation channels and lack of research on smart sluice gate and manual sluice gate to further investigate in terms of equipment efficiency and water removal from each sluice gate.

The research is aims to investigate the efficiency of the gate opening of the smart sluice with the manual sluice, so that the advantages and disadvantages of each sluice gates can be identified and investigate the variation of water discharge generated by smart sluice gates and manual sluice gates.

2. Water discharge analysis

According to the USA Department of the Interior Bureau of Reclamation [6] and Kraatz [7], it was said that water flow through sluice gate has long been the subject of various theoretical analyzes, and laboratory and field experiments. Depending on the depth of water downstream of the gate from its edge, two hydraulic conditions can be distinguished: free flow and submerged. The free flow condition occurs when the
downstream water depth was below the inverted gate and the downstream water depth has no effect on the flow below the gate. Submerged flow means an increase in the water level downstream over the reverse gate and downstream water affects the water depth upstream. Based on various hydraulic experiments, the value of the discharge coefficient used in the one-dimensional formula was determined, relating the depth of upstream and downstream water, the gate, and the gate opening height and width with the water flow rates for these two flow forms. Most of these experiments were carried out on a flume with a horizontal base, rectangular cross-section and width, corresponding to the gate width.

The use of these formulas and coefficients to determine flow rates for submerged gate exits in the hydraulic structure of irrigation canals, such as entrances, requires clarification of many issues. In finding the water The Discharge at a sluice opening in the irrigation stream, you can use the bernoulli formula. Based on the submerged hole equation, the formula for determining the discharge coefficient \(C_d\) [8] and the measurement of the sluice gate flow rate for engineering equipment uses the bernoulli equation described by the Engineering Toolbox [9] as follows:

\[
\frac{1}{2} \rho v_1^2 + \rho g h_1 = \frac{1}{2} \rho v_2^2 + \rho g h_2
\]

(1)

Where \(h\) is elevation height (m), \(\rho\) is density (kg/m\(^3\)), \(v\) is flow velocity (m/s)

The pressure components in the equation are in general irrelevant since pressure upstream and downstream are the same \((p_1 - p_2 = 0)\).

Assuming uniform upstream and downstream velocity profiles - the Continuity Equation gives:

\[
q = v_1 A_1
= v_2 A_2
\]

(2)

Where \(q\) is flow rate (m\(^3\)/s), and \(A\) is flow area (m\(^2\))

(2) can be modified to:

\[
q = v_1 h_1 b
= v_2 h_2 b
\]

(3)

Where \(b\) is width of the sluice (m), \(h_1\) is upstream height (m), and \(h_2\) is downstream height (m)

Combining (1) and (3), gives the "ideal" equation:

\[
q = h_2 b \left[ 2 g (h_1 - h_2) / (1 - (h_2 / h_1)) \right]^{1/2}
\]

(4)

Assuming \(h_1 \gg h_2\) (4) can be modified to:

\[
q = h_2 b \left[ 2 g h_1 \right]^{1/2}
\]

(5)

This is approximately true when the depth ratio \(h_1/h_2\) was large, the kinetic energy upstream is negligible \((v_1\) is small) and the fluid velocity after it has fallen the distance \((h_2 - h_1) \approx h_1\) - is:

\[
v_2 = \left[ 2 g h_1 \right]^{1/2}
\]

(6)

The ideal equation (3) can be modified with a discharge coefficient:
\[ q = \frac{c_d \cdot h_2^2}{h_1^{1/2}} \tag{7} \]

Where \( c_d \) is discharge coefficient

The discharge coefficient depends on different parameters - such as upstream and tail-water depths, gate opening, contraction coefficient of the gate and the flow condition. In practice the typical discharge coefficient is approximately \( 0.61 \) for free flow conditions and depth ratios \( h_0/h_1 < 0.2 \).

The equation used to calculate the value of \( c_d \) [8]:

\[ c_d = \frac{q}{a \cdot \sqrt{g \cdot H}} \tag{8} \]

Where is the information on the analysis components as follows: \( q \) is discharge (cm\(^3\)/s), \( c_d \) is discharge Coefficient, \( a \) is cross-sectional Area (cm\(^2\)), \( g \) is gravity force (m/s\(^2\)), and \( H \) is difference in water level (cm).

**Figure 1.** Submerged flow under the gate: (a) water depth \( h_z \) immediately downstream of the gate is noticeably lower than the downstream water depth \( h \) (\( h_z < h \)), (b) the tailwater curve is always above the jump curve (\( h_z > h \)) [10]

Sluice, later confirmed by Rajaratnam and Subramanya [11], developed a dependency regression for the discharge coefficient \( C_d \). In the case of free flow conditions, the discharge coefficient depends on the depth of the top water. Bernoulli’s law states that the amount of water energy from each flow that passes through a channel cross-section can be expressed as the number of functions of water, pressure height and velocity.

**3. Research method**

The research Location, the laboratory testing did in Hydraulics Laboratory SV UGM. Study of literature, reviewing from books, articles in journals and other library tools that support the investigation of the performance of smart sluice gate and manual sluice gate.

Research procedure, laboratory tests is carrying out to investigate manual sluice gate with smart sluice gate, carried out by looking for water discharge and discharge coefficient, then comparing manual sluice gate with smart sluice gate.
The scenario of the irrigation flow is watered then the sluice gates are opened, the manual sluice gate are opened every 10 cm because there are 10 cm intervals and 5 cm smart sluice scenarios between openings to get more variety of openings than manual sluices, smart sluice gate that do not have gate opening restrictions can be arranged according to the user's wishes to the height of the irrigation opening. The analysis of the water discharge at each sluice gate is using the bernoulli equation as a reference for calculating the water discharge at the sluice gate. Furthermore, the sluice efficiency analysis is carrying out, then to interpret the data from the analysis of the sluice efficiency as a percentage, the following steps are required [12]:

\[
\text{Percentage of value (\%)} = \left(\frac{\text{value obtained}}{\text{maximum value}}\right) \times 100
\]  

(9)

Data presentation method, the results of the research are arranged descriptively and visually graphically in accordance with the concepts applied in the research design.

4. Result and discussion
Testing in this study is carried out by comparing the sluice openings between the manual sluice gate and the smart sluice gate, while the smart sluice gate scenario used the gearbox model, the manual sluice gate used a hole in the middle of the sluice frame and each hole in the manual sluice is 10 cm apart. as a buffer for openings, on the other hand, the smart sluice gate uses a gearbox sluice model with gate openings without intervals between openings, with a motor as the driving force and a microcontroller as an opening regulator. automatic and realtime combined with sensors. Accordingly, the investigate in this study is to see the water discharge to the manual sluice gate and smart sluice gate, and to see the efficiency of each sluice gates, in Figures 2 and 3 the results of the analysis between manual sluice gate and smart sluice gate are illustrated in a graph.

![Figure 2. Discharge of Manual Sluice Gate Result](image)

Based on the graph in Figure 2, The manual sluice openings are carrying out up to 100 cm. Then from the results of the discharge analysis obtained from each variation of manual sluice openings is 4.16 m³/s, 16.63 m³/s, 37.42 m³/s, 66.52 m³/s, 103.93 m³/s, 149.67 m³/s, 203.71 m³/s, 266.07 m³/s, 336.75 m³/s, and 415.74 m³/s, where g as gravity is 9.81 m/s, the analysis is carried out by the barnoulli equation.
Figure 3. Discharge of Sluice Gate Result

The smart sluices is using sluice gate with gearboxes have more variations of sluice openings, based on the graph in Figure 3, the researchers used an opening interval of 5 cm. The results of the analysis of water discharge with the smart sluice scenario at each sluice opening are 4.16 m$^3$/s, 9.35 m$^3$/s, 16.63 m$^3$/s, 25.98 m$^3$/s, 37.42 m$^3$/s, 50.93 m$^3$/s, 66.52 m$^3$/s, 84.19 m$^3$/s, 103.93 m$^3$/s, 125.76 m$^3$/s, 149.67 m$^3$/s, 175.65 m$^3$/s, 203.71 m$^3$/s, 233.85 m$^3$/s, 266.07 m$^3$/s, 300.37 m$^3$/s, 336.75 m$^3$/s, 375.21 m$^3$/s, 415.74 m$^3$/s.

Figure 4. Comparison Discharge of Sluice Gate Result

The discharge between manual and smart sluice gates gets different variations. Thus, different variations in water discharge are obtained. Based on these results, the smart sluice gate effective in regulating the discharge of water according to agricultural needs. The investigate of the discharge at the manual sluice gate and smart sluice gate can be seen in the graph in Figure 4. There are several numbers same because the opening height is the same in several variations. However, the smart sluice gate discharge is stating more varied because there is no interval in the gate opening contained in the middle frame as a buffer for gate openings such as manual sluice gate so that smart sluice gate are excelling in this case. according to research conducted by Albas and Permana [13] regarding the study of the effect of sluice gate.
openings, variations in gate openings affect the discharge of water emitted, the more efficient the sluice gates, the variations in openings vary and the discharge the objective will vary.

Figure 5. Comparison Efficiency of Sluice Gate Result

Based on the graph in Figure 5, it is stating that the efficiency of the sluice gate between manual sluice gate and smart sluice gate is different in that the variations in the openings variations of smart sluice gates are more varied as the result of the discharge analysis in the previous study that manual sluice openings are limited to only 10 variations, whereas on the smart sluice gate openings can be varied so that the openings are 19 variations with the scenario of openings every 5 cm, but smart sluice gate using a gearbox can be done with a wide variety of sluice openings. Based on the results of the efficiency analysis, it was found that the efficiency at manual sluice openings from 10 variations obtained the value of 3.91 (1%), 16.38 (4%), 37.17 (9%), 66.27 (16%), 103.68 (25%), 149.42 (36%), 203.46 (49%), 265.82 (64%), 336.50 (81%), and 415.49 (100%). Furthermore, the results of the analysis of the efficiency of smart sluice openings are 3.91 (1%), 9.10 (2%), 16.38 (4%), 25.73 (6%), 37.17 (9%), 50.68 (12%), 66.27 (16%), 83.94 (20%), 103.68 (25%), 125.51 (30%), 149.42 (36%), 175.40 (42%), 203.46 (49%), 233.60 (56%), 265.82 (64%), 300.12 (72%), 336.50 (81%), 374.96 (90%), and 415.49 (100%). Based on the analysis of sluice efficiency. Manual sluice gate obtained the largest values, namely 336.50 (81%), and 415.49 (100%), while the smart sluice gate were, 300.12 (72%), 336.50 (81%), 374.96 (90%), and 415.49 (100%), afterwards, the efficiency of the sluice gate is more varied in the smart sluice scenario, which means that the performance of the smart sluice device is better than the manual sluice gate.

5. Conclusion
Based on the results of the tests carried out, it is concluding that there are scenarios for testing water discharge and efficiency at each sluice gate there are several values same because the opening height is the same in certain variations. However, the discharge and efficiency of smart sluice gate are more varied investigated to 19 variations of openings investigated to manual sluice gates which are only limited to 10 variations of sluice openings. According to the analysis conducted shown the investigate of the discharge at the manual sluice gate and smart sluice gate there are several numbers same because the opening height is the same in several variations. However, the smart sluice gate discharge is stating more varied because there is no interval in the gate opening contained in the middle frame as a buffer for gate openings such as manual sluice gate so that smart sluice gate are excelling in this case. The efficiency in manual sluice openings with 10 variations obtained an average of 49%, while the smart sluice openings with a 5 cm open scenario,
variations in gate openings can be carried out continuously, the average result of the smart sluice efficiency analysis is 72%, so the smart sluice has a greater efficiency value than the manual sluice gate.

6. References

[1] Suroso D S A Hadi TW Salim W 2009 Indonesia Climate Change Sectoral Roadmap (Jakarta: Bappenas)

[2] Manez K S Husain S Sebastian Ferse S C A and Costa M M 2012 Water scarcity in the Spermonde Archipelago, Sulawesi, Indonesia: Past, present and future environmental science & policy. 23 pp 74-84

[3] Ministry of Agrarian Affwaters and Spatial Planning of the Republic of Indonesia 2016 Regulation of the minister of agrarian affwaters and spatial planning / head of the national land agency no. 19 of 2016 concerning stipulation of sustainable food agricultural land in areas that have not yet been formed a regional spatial plan (Jakarta: Ministry of Agrarian Affwaters and Spatial Planning /National Land Agency)

[4] Colantoni A, Monarca D, Laurendi V, Villarini M, Gambella F and Cecchini M 2018 Smart machines, remote sensing, precision farming, processes, mechatronic, materials and policies for safety and health aspects Agriculture 8(47) pp 1-14.

[5] Bappenas 2019 Projection of indonesian water availability (Jakarta: Kajian Lingkungan Hidup Strategis (KHLS) RPJM 2019)

[6] USA Department of the Interior Bureau of Reclamation 2001 Water measurement manual (USA: Ephrata,WA)

[7] Kraatz D B 2002 Small hidraulic structures Paper 26/2 FAO Irrigation and Drainage (Rome, Italy)

[8] Herdianto D O Siswanto and Rinaldi 2015 Water gate model in tidal areas to reduce sea water intrusion. Jom Fteknik 2 (2)

[9] Engineering Toolbox 2004 Sluice gate flow measurements [online] Available at: https://www.engineeringtoolbox.com/sluice-gate-flow-measurement-d_591.html [Accessed 28 October. 2020].

[10] Kubrak E Kubrak J Kiczko A and Kubrak M 2020 Flow Measurements Using a Sluice Gate; Analysis of Applicability Water. 12 pp 819

[11] Rajaratnam N Subramanaya K 1967 Flow equations for the sluice gate J. Irrig. Drain. Eng. ASCE 93 pp 167–186.

[12] Muhammad A 1993 Educational research procedures and strategies (Bandung: Angkas) p 186

[13] Albas J and S Permana 2016 Study of the effect of opening high water gates Journal of Construction. 14 (1)

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