Correlation between Pump Discharge and Operational Cost of Polder System: Case Study of Pekalongan Regency

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Abstract: The coastal area in Pekalongan has a big problem of flood that is caused by rain and tidal flood. To overcome the situation, in 2018-2019, a drainage with polder system has been built at Mriran-Wonokerto area, Pekalongan Regency, equipped with the 5 km embankment and long storage. The aim of this study was to acquire correlation model between pump discharge and fuel oil consumption of Mriran-Wonokerto Polder System and to conduct simulation of operational cost from the fuel oil to the electricity provided by PLN. The method used is quantitative method with daily data in the form of pump operation record of Silempeng and Sengkarang pump houses. The analysis results indicated that the equation of the relation between the pumping volume capacity (X) (in m³) and fuel oil consumption (Y) (in liter) of Silempeng and Sengkarang pump house were linear equations. The equations were Y = 0.2509 + 0.0044X with a correlation coefficient (r) of 0.928 for Silempeng and Y = 0.5608 + 0.0035X with r=0.981 for Sengkarang. The equation of relation between the actual pumping volume and fuel oil consumption during the absent of rain was Y=0.5292+0.0067X with r=0.8328, while the rainy days was Y=0.6605+0.0055X with r=0.8329. The simulation of change from propulsion of diesel pump machine to electric propulsion proofed that the change could generate efficiency 45.12% at Silempeng and 30.53% at Sengkarang pump house in the aspect of operational cost. The results of this study are used to a guidance for pump operational financing by the government.

1. Introduction
Pekalongan Regency is one of the regions in Central Java Province located in the North coast of Java Island. Similar to any other coastal areas of the Northern Java, Pekalongan coastal area has major problem of flood caused by rain and the intrusion of seawater to residential areas commonly called as a tidal flood (rob). Several contributing factors of tidal flood include land subsidence, global warming, exaggerate groundwater capitalization, deforestation of mangrove forest, topographic condition, changes in marshland, lake, rice field and any other area utilization, as well as riverbank narrowing, littering at rivers and poorly maintained drainage system. [1].

Water absorption region is crucial for urban areas due to its benefit for groundwater preservation or the environmental water resources stability. A constant degradation of water absorption region might result in various kinds of environmental issues such as high surface water discharge that might cause a local flood if it was beyond the catchment area storage discharge of the area. [2]. It has been predicted that the prevalence of coastal flood will going to be higher due to the rise of the sea level along the Pekalongan coast (approximately 4.46-4.60 mm/year) [3] and land subsidence. The flood and the coastal flood in Pekalongan regency mainly affect Siwalan, Wonokerto and Tirto Sub-District. [4]. In order to overcome the situation, a drainage with polder system and a modern water management is required [5].
In the period of 2018-2019, the Ministry of Public Works and Public Housing, Directorate General of Water Resources, the Main Office of Pemali Juana River Area have built a polder-system drainage in Mrican-Wonokerto. Some researches about polder system in Pekalongan Regency have been conducted, including a research on the spatial modelling of the danger of tidal flood based on the climate change scenario and their impacts [6] and on the handling of tidal flood in Pekalongan which covers the aspect of working location condition, physical handling and causes of tidal flood [1]. The other researches concern on the hydrologic simulation the flood controller river situated in Wonokerto, the Regency of Pekalongan [7]. Meanwhile, a research on pump operational cost has also been conducted for the power supply election of the Grenes pump, Surabaya [8]. This study aims to determine the correlation between pump capacity, pumping volume and pump operating costs as well as to simulate the operational costs of replacing fuel with PLN power. The polder system is a system that is hydrolologically separated from its surroundings both naturally or artificially way, and this system is equipped with embankment, an internal drainage system, a retention basin pump and a watergate [9]. In this polder system, the flood discharge in the catchment area are streamed through a drainage to be collected in the retention basin (polder), from which water retention basin is pumped into rivers or seas [10]. The simulation scheme of retention basin capacity can be seen in the figure 1:

![Figure 1 Simulation System of Retention Basin Capacity](image)

The above simulation depicts a retention basin accommodating $Q_{\text{flood}}$ and a pump with a capacity of $P$, so it requires the following continuity law [12]:

$$Q_{\text{flood}} = P + \frac{d_s}{d_t}$$

in which:

- $Q_{\text{flood}}$ = the entering flood debit collected in the retention basin (m³/second)
- $P$ = the capacity of the pump streaming the water out of the retention basin (m³/second)
- $\frac{d_s}{d_t}$ = alteration rate of the water deposit in the basin as the function of time (m³/detik)

2. Methodology
This study used quantitative method, whose data were in the form of numbers and collected through surveys and observation. The daily data were about pump operation in Silempeng and Sengkarang pump house from January 2020 to May 2020 provided by the Main Office of River Area (BBWS) Pemali Juana, Semarang. BBWS provide data for each hour during operation.

The locations of this research were the sub drainage system of common flood and coastal flood handling between Silempeng River and Sengkarang River of the administration area of Wonokerto Sub-district, the Regency of Pekalongan. The locations were grouped into two sections namely section-1 dan section-2 [13]. Section-1 with length of water storage = 2,850 m, width of water storage = 30 m and section-2 with length of water storage = 2,205 m, width of water storage = 30 m. The table 1 presents the CA (Catchment Area) that brought an effect to the Mrican-Wonokerto system.
### Table 1 Catchment Area of the Mrican Wonokerto system

| NO | Channel            | CA Area (km²) | Channel Lenght (km) |
|----|--------------------|---------------|---------------------|
| 1  | Semut River        | 2.54          | 1.757               |
| 2  | Mrican River       | 4.16          | 7.911               |
| 3  | Tratebang River    | 4.53          | 5.006               |
| 4  | Pekuncen River     | 2.71          | 3.917               |
| 5  | Pesanggrahan River | 3.11          | 4.172               |
|    | TOTAL              | **17.95**     |                     |

The rivers included in Mrican-Wonokerto drainage system can be seen in figure 2 and figure 3.

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Figure 2 Map of Mrican – Wonokerto Drainage System, Pekalongan Regency

Silempeng Pump House consist of 2 (two) pump units with the capacity of 2.00 m³/second each. The pump type was *electric submersible*. Sengkarang Pump House consist of 3 (three) pump units with the capacity of 2.00 m³/second each. The pump type was *axial line shaft*. The pumps were operated at water elevation, with a maximum rate of +1.90 and minimum rate of +1.00, in the retention basin.

To find the relation between the variables in the form of equation, it needed a simple linear regression which was:

\[ Y = \alpha + \beta \times X \]  

(2)

which describes a line with slope \( \beta \) and y-intercept \( \alpha \) [14].

In the analysis of the relation between pumping volume capacity and fuel oil consumption, the independent variable \( (X) \) was the pumping volume capacity while the dependent variable \( (Y) \) was the fuel oil consumption.
3. Result and Discussion

3.1. The Correlation between Pumping Volume Capacity and Fuel Oil (BBM) Consumption

The pumping volume capacity was calculated according to the pumping volume where the debit of every pump unit was multiplied by the duration of pump operation in a day. Meanwhile, the fuel oil consumption was calculated by using the record of the daily spending of fuel oil for the operation of the pump.

To find the relation between the two variables, a correlation analysis needed to be conducted. The correlation was in the form of numbers indicating the strengths of both variables influence [15]. The influence could be either positive or negative while the strength of the relation was indicated by the enormity of the correlation coefficient.

3.1.1. Silempeng Pump House

From the record provided by Silempeng Pump House, it was known that the equation between the variables was \( Y = 0.2509 + 0.0044X \), with the correlation coefficient \((r)\) of 0.928. This result indicated that the relation between the two variables was considerably strong. The shape of the relation can be seen in the figure 4.

![Figure 4](image_url)

**Figure 4.** Graphic of Correlation between Pumping Volume and Fuel Oil Consumption in Silempeng Pump House

3.1.2. Sengkarang Pump House

From the record provided by Sengkarang Pump House, it was known that the equation between the variables was \( Y = 0.5608 + 0.0035X \), with the correlation coefficient \((r)\) of 0.981. This result indicated that the relation between the two variables was considerably strong. The shape of the relation can be seen in the figure 5.

![Figure 5](image_url)
Figure 5. Graphic of Correlation between Pumping Volume and Fuel Oil Consumption in Sengkarang Pump House

3.2. Analysis of Correlation Between Actual Pumping Volume and Fuel Oil Consumption

The analysis of correlation between the actual pumping volume and fuel oil consumption was classified into two groups namely the group of ‘days without rain’ and the group of ‘rainy days’. It was classified in accordance with the daily precipitation data from Meteorology, Climatology, and Geophysical Agency of Semarang Climatology Station, based on the rainfall recording station STA Wiradesa of Regency Pekalongan.

3.2.1. Days without Rain

Under this circumstance, the water input in the long storage is extremely low so it was perceived that the said water input in the long storage was \(0 \text{ m}^3\) during the pumping, that the water volume within long storage did not increase. This stream merely came from households and industries. The actual pumping volume was a total water volume in retention basin pumped out of during pump operation, and it can be measured using:

\[
Pumping \text{ volume} = \text{height difference} \times \text{storage area}
\]  

The Mrican – Wonokerto drainage system, which was equipped with 2 (two) pump houses, has been connected with a long storage, merging as a single drainage system. The length of the long storage was 5,055.00 meters, while the width was 30.00 meters and the area was 151,650.00 \(\text{m}^2\). As the pump houses operated jointly, the measurement of height difference was conducted by measuring the average results of water decline reading within both pump houses, while the fuel oil consumption was measured by summatiing both pump houses’s.

Regression analysis was conducted according to the recording data from Sengkarang and Silempeng pump houses and the correlation equation was \(Y = 0.5292 + 0.0067X\), in which the correlation coefficient \((r)\) was 0.8328. The correlation form can be seen from the figure 6.

Figure 6. Graphic of Correlation between Actual Pumping Volume and Fuel Consumption in Condition without Rain
3.2.2. Rainy Days
In rainy condition, watercourse flows to the long storage. The actual pumping volume during rainy days was a total water volume in retention basin added with water volume generated from the rain. Therefore, the actual volume pumped for 24 hours can be measured using:

\[ \text{Pumping volume} = (\text{height difference} \times \text{storage area}) + \text{Volume of rainfall-runoff} \] (4)

in which:
- Height difference = difference between initial and final water elevation (m)
- Retention basin area = long storage area (m²)
- Volume of rainfall-runoff = rainfall-runoff for 24 hours (m³)

Measurement of rainfall-runoff volume constituted water discharge (Q) for 24 hours, water discharge (Q) is measured using the following formula (2.2):

\[ Q = \alpha \beta I_t A \] (5)

where:
\[ \alpha = 0.225, \ \beta = 0.941, \ A = 17.05 \text{ km}^2 \]

\[ I_t = \left( \frac{R}{24} \left( \frac{T_c}{T_c} \right) \right)^{2/3} \] (6)

where:
- R = duration, rainfall (mm)
- \( T_c = 0.0195 \left( \frac{L}{S} \right)^{0.77} \) (7)
- L = 4,552.60 m
- S = 0.000439

It is obtained that \( T_c = 4,919.96 \text{ minutes or 82.00 hours.} \)

by using \( T_c \), it can be obtained that \( I_t = \left( \frac{R}{24} \left( \frac{24}{82} \right) \right)^{2/3} = 0.0184 \cdot R \) (8)

\[ Q = 0.0063 \cdot R \], the volume of rainfall-runoff for 24 hours is:

\[ V = (0.0063 \cdot R \times 86,400) \text{ m}^3 \] (9)

From the recording data in Sengkarang and Silempeng pump houses, upon conducting data analysis, it was obtained that the equation of the relationship between the variables was \( Y = 0.6605 + 0.005X \), with the correlation coefficient (r) of 0.8329, meaning that the fuel consumption was affected by the volume of actual pumping. The relationship form can be seen from figure 7.

![Figure 7 Graphic of Correlation between Actual Pumping Volume and Fuel Consumption in Rainy Days](image-url)
Based on the regression equation, pump simulation between flood discharge \( (Q_{\text{flood}}) \), flood volume, fuel requirements and water level elevation was implemented. The graphic of the simulation is as figure 8.

![Figure 8. Graphic of Correlation between Water Discharge, Volume, Fuel and Water Level of Mrican - Wonokerto Pump System](image)

### 3.3. Simulation of Diesel Pump Replacement by Electric Power Pump

Silempeng and Sengkarang pump employed diesel engine power plants with diesel oil. In this analysis, the replacement of electric power plant (PLN) for Silempeng \((1 \times 2 \text{ m}^3/\text{second})\) and Sengkarang \((2 \times 2 \text{ m}^3/\text{second})\) was simulated.

#### 3.3.1. Silempeng Pump House

Silempeng pump used submersible pump manufactured by *Grundfos* with motor specification of 3 phases power supply, the voltage of 380 V, the frequency of 50 Hz, and the rated power of 160 kW. Thus, power consumption per hour was \(= 160 \text{ kW} \times 1 \text{ hour} = 160 \text{ kWh} \). In accordance with electricity rate of PLN (State Electric Company) dated December 30, 2019 for the class B-3 TM, amounting IDR\(1,035.78 / \text{kWh} \), the cost per hour would be \(160 \times \text{IDR}1,035.78 = \text{IDR}165,724.80 \). The calculation of operation cost while using fuel oil according to the basic price of diesel oil by Pertamina (for the period of June 15 – 30, 2020) was IDR 9,448.43.

Based on the operating data from Silempeng pump house in January 2020 to May 2020, here is the analysis of the cost comparison between fuel consumption and PLN electric power consumption. From the figure 9, it can be seen that in February and March, the monthly operational costs increase due to high rainfall.

![Figure 9. Comparison of Monthly Operational Cost in Silempeng Pump House using Fuel and Electricity](image)
From the analysis of recording data from the pump operation in Silempeng pump house, it can be simulated as seen in Figure 10.

**Figure 10.** Simulation of Power Consumption with Fuel and Electricity in Silempeng Pump House.

From the comparison between the operating costs resulted from diesel engine power (with diesel oil) and electric power from PLN in Silempeng, it was obtained that the equation was:

- The operating cost when using fuel oil (BBM): \( Y = 293,619X + 290,954 \).
- The operating cost when using electric power: \( Y = 165.725X \).

It can be concluded that the average cost of electricity usage is 45.12% cheaper than fuel consumption.

### 3.3.2. Sengkarang Pump House

Sengkarang pump employed axial pump manufactured by KSB with motor specification of 3 phases power supply, voltage of 380 V, frequency of 50 Hz and the rated power of 200 kW. Hereby, electric consumption per hour was \( 200 \text{ kW} \times 1 \text{ hour} = 200 \text{ kWh} \). In accordance with electricity rate of PLN (State Electric Company) dated December 30, 2019 for the class B-3 TM amounting IDR1,035.78 / kWh, the cost per hour was \( 200 \times \text{IDR} \times 1,035.78 = \text{IDR} 207,156.00 \). The calculation of fuel consumption cost was based on diesel oil pricing from Pertamina for the period of June 15-30, 2020, amounting IDR9,448.43.

According to operating data from Sengkarang pump house in January 2020 to May 2020, here is the cost analysis between fuel consumption and PLN electric power consumption as described in the figure 11, it can be seen that in February and March, the monthly operational costs increase due to high rainfall.

**Figure 11.** Comparison of Monthly Operational Cost in Sengkarang Pump House using Fuel and Electricity.
Based on the recording data of pump operation in Sengkarang pump house, it can be simulated as seen in figure 12.

![Figure 12. Simulation of Power Consumption with Fuel and Electricity in Sengkarang Pump House.](image)

From the comparison between the operating costs of diesel engine power (with diesel oil) and electric power of PLN in Sengkarang, the equation was:

- The operating cost when using fuel: \( Y = 15,032 + 297,766X \)
- The operating cost when using Electric Power: \( Y = 207,156X \).

It can be concluded that the average cost of electricity usage is 30.53% cheaper than fuel consumption.

4. Conclusion
The correlation of pumping volume capacity with fuel consumption in Silempeng Pump House, was described in the linear equation regression of \( Y = 0.2509 + 0.0044X \), with a correlation coefficient \( (r) \) of 0.928. Meanwhile, in Sengkarang pump house, a linear regression equation of \( Y = 0.5608 + 0.0035X \), with correlation coefficient \( (r) \) of 0.981. The correlation between actual pumping volume and fuel oil consumption during days without rain was \( Y = 0.5292 + 0.0067X \), with the correlation coefficient \( (r) \) of 0.8328. A linear regression equation of \( Y = 0.6605 + 0.005X \), with correlation coefficient \( (r) \) of 0.8329, can be obtained under rainy circumstance.

The comparison between the operating costs of diesel engine power (using diesel oil) and electric power of PLN is (a) in Silempeng pump house, it is obtained an equation of \( Y = 290,254 + 293,619X \) for the operating cost when using fuel, and \( Y = 165,725X \) for the operating cost when using electric power. Therefore, PLN electric power consumption is 45.12% more efficient in regard with the financing aspect. (b) It can be obtained an equation of \( Y = 15,032 + 297,766X \) for the operating cost when using Fuel, and \( Y = 207,156X \) for the operating cost of Electric Power in Sengkarang pump house. Thus, power consumption using PLN electric power is 30.53% more efficient for the financing aspect. The results of this study are used as a guidance for pump operational financing by the government.

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