BIO Web of Conferences **157**, 05003 (2025) https://doi.org/10.1051/bioconf/202515705003
SRCM 2024

Study of Sludge Accumulation Rate and Sediment Distribution in Kalidami Boezem, Surabaya

Umi Aisyah[1], *Ervin* Nurhayati [1*], *Agus* Slamet[1], *Ali* Masduqi[1], *Eddy* Setiadi Soedjono[1], *Bowo* Djoko Marsono[1], and *Isni* Arliyani[1]

[1]Department of Environmental Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia

Abstract. Kalidami Boezem is one of Surabaya City's boezems that is used as a flood control. This boezem can experience silting due to solids that settle from domestic wastewater entering the boezem. This causes decrease in Kalidami Boezem's volume. The implementation of sludge dredging as boezem maintenance has not been based on accumulation of deposited sludge and sediment distribution. The research included analysis of degradation rate, total solid, and total suspended solid. Sludge sampling was conducted once at inlet, middle, and outlet boezem. Sludge degradation rate was analyzed for 25 days with gravimetric analysis and reaction kinetics approach. Water sampling for sludge accumulation rate analysis was conducted for 7 consecutive days. Sludge accumulation rate was calculated based on the difference in total solid at inlet and outlet. Water sampling for sediment distribution mapping was conducted 3 times a week. Sampling points for sediment distribution mapping amounted to 15 points based on transects 60 m x 30 m. The results of TSS analysis from each transect will be mapped using Surfer 23. Degradation rate of sludge in Kalidami Boezem is 0.0005/day. Sludge occupies 1.65% of the effective storage boezem's volume with accumulation rate of 1780.484 m^3/year. Sediment distribution decreased from inlet to outlet due to settling velocity, flow based on Reynold's number, settling velocity, flow velocity at each transects point, dredging, and pumping activities. The settling velocity is greater than the water flow velocity so that more solids are sedimented at the inlet of the boezem.

1. Introduction

Boezem development is a strategy of Surabaya City in flood control and increasing water catchment areas based on Surabaya City Regional Regulation Number 12 of 2014 concerning the Surabaya City Regional Spatial Plan 2014-2034. Kalidami Boezem is one of the boezems in Surabaya City with a catchment area covering Mulyorejo, Gubeng, and Sukolilo sub-districts. This boezem can experience siltation due to the high amount of domestic wastewater

---

[*] Corresponding author: ervin@its.ac.id

that enters the boezem along with rainwater from the drainage channels of the boezem catchment area.

Several areas within the Kalidami Boezem exhibit green and black discoloration, accompanied by unpleasant odors emanating from the water. These conditions are likely attributed to the sedimentation of solid particles originating from domestic wastewater. Sedimentation occurs when the velocity of solid particles entering the boezem is insufficient to counteract their settling velocity, allowing them to accumulate over time [1]. The presence of these deposits can cause turbidity caused by Total Suspended Solid (TSS) levels in water bodies [2]. Organic compounds in TSS as indicated by the Total Volatile Suspended Solid (TVSS) value cause biodegradation which results in odor. Sediment will silt up the boezem and reduce the removal of wastewater concentration in the boezem. This condition results in reduced water storage capacity due to sludge accumulation at the bottom of the boezem [3].

Sludge dredging is conducted on a biannual basis by the Water Resources and Bina Marga Agency with the objective of maintaining the operational capacity of the boezem, ensuring its continued functionality as a flood control mechanism. The dredging is not yet based on the overall volume of sludge. It is necessary to consider the concentration of sediment in the dredging area in order to ensure the sustainability of the dredging process [4]. Sediment distribution analysis was conducted using Surfer 23 software. The parameter processed in the sediment distribution in this software is TSS. Surfer 23 was chosen because it has high compatibility in various types of data.

2. Materials and Methods

There are water samples and sludge samples. Water samples were used for TS, TSS, settleable solid, and settling velocity analysis while sludge samples were used for degradation rate analysis. Sludge sampling was conducted once at the inlet, middle, and outlet of the boezem. Water sampling for sludge accumulation rate analysis was conducted once a day for 7 consecutive days at the inlet, middle, and outlet of the boezem. Water sampling for sediment distribution mapping was conducted 3 times a week for 2 days at a time. Sampling points for sediment distribution mapping amounted to 15 points (points numbered 3 to 17 in **Figure 1**) based on transects with a length and width of 60 m x 30 m per transect.

Figure 1. Sampling Location of Kalidami Boezem.

The research was carried out by measuring the flow rate using current meter in accordance with SNI 3408: 2015 procedures. The segmentation was conducted in the measurement of flow rate. The inlet and center of the boezem were divided into four segments, with the width of each segment obtained by dividing the total channel width into four parts. Measurement of the cross-sectional area of each segment was approached following the principle of a triangular shape in segments 1 and 4. For segments 2 and 3, measurements were made using a combined rectangular and triangular approach.

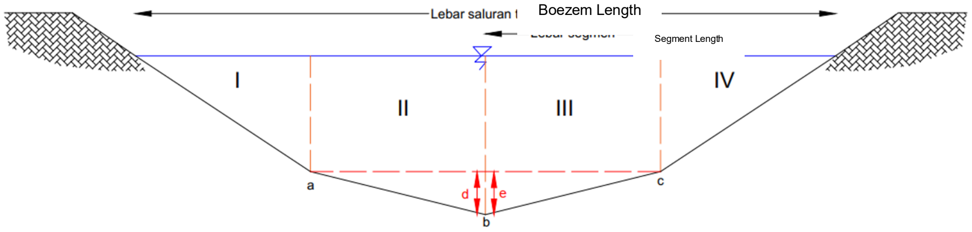


Figure 2. Inlet and Center of Kalidami Boezem's Segmentation.

3. Result and Discussion

3.1. Analysis of Flow Rate

Table 1. Flow rate of Boezem Kalidami

Sampling date	Segment	Wet cross-sectional area (A)	Felocity (v)	Flow rate per segment	Total flow rate
		m^2	m/s	m^3/s	m^3/s
Inlet					
25 March 2024	I	10.26	0.023	0.235	1.513
	II	15.69	0.038	0.598	
	III	10.09	0.053	0.538	
	IV	4.66	0.03	0.142	
27 Mar ch2024	I	8.67	0.03	0.264	1.133
	II	12.89	0.023	0.295	
	III	8	0.061	0.488	
	IV	3.78	0.023	0.086	
01 April 2024	I	8.13	0.03	0.248	1.206
	II	13.57	0.023	0.31	
	III	9.21	0.061	0.562	
	IV	3.78	0.023	0.086	
Average inlet flow rate (Q) (m^3/s)					**1.284**
Center					
25 March 2024	I	17.63	0	0	0.33
	II	43.28	0.025	0.33	
	III	47.18	0	0	
	IV	21.53	0	0	
27 March 2024	I	16.8	0.025	0.128	0.903
	II	40.43	0.025	0.308	
	III	42.45	0.025	0.323	
	IV	18.83	0.025	0.143	
01 April 2024	I	16.05	0	0	0.607
	II	38.93	0.025	0.297	
	III	40.73	0.025	0.31	

Sampling date	**Segment**	**Wet cross-sectional area (A)**	**Felocity (v)**	**Flow rate per segment**	**Total flow rate**
		m^2	**m/s**	**m^3/s**	**m^3/s**
	IV	17.85	0	0	
Average center flow rate (Q) (m^3/s)					**0.613**
Outlet					
25 March 2024	I	0	0	0	0.139
	II	3.24	0	0	
	III	3.57	0	0	
	IV	3.66	0.125	0.139	
27 March 2024	I	0	0	0	0.07
	II	3.05	0	0	
	III	2.96	0	0	
	IV	3.06	0.075	0.07	
01 April 2024	I	0	0	0	0.082
	II	3.2	0	0	
	III	3.44	0	0	
	IV	3.57	0.075	0.082	
Average outlet flow rate (Q) (m^3/s)					**0.097**

The obtained flow rate at the inlet is 1.292 m^3/s and the flow rate in the center of the boezem is 0.613 m^3/s. Since the sluice gate at the outlet of the boezem was not operated during measurement, the outlet flow rate is assumed to be the same as the inlet discharge of 1.292 m^3/s because there is no water flowing at the outlet. This indicates a decrease in water flow discharge from the inlet to the outlet. This decrease can also be seen in the flow velocity in the middle of the boezem and the outlet of the boezem, which is zero because the water flow velocity is so low that it cannot be read by the current meter. This can be caused by the slower flow pattern of the Kalidami boezem inlet because it has lost its potential energy from upstream to downstream along the Kalidami channel [5]. This condition may be different if measurements are taken at the peak of the rainy season when the water discharge from the Kalidami channel is greater. The condition of the Kalidami channel in the dry season contains wastewater from the surrounding settlements, which tends to have a small discharge, while in the rainy season, the volume and speed of water flow in the Kalidami channel increases, resulting in an increase in the incoming discharge [6].

3.2. Analysis of Total Solid

The points analyzed were 3 with point 1 being the boezem inlet, point 9 being the middle of the boezem, and point 2 being the boezem outlet. From **Figure 3**, total solid concentration fluctuated during the 7 days of measurement. The highest total solid concentration was on the third day of measurement. This may occur because the third day is a working day where the water use activities of the surrounding community increase in the morning, thus affecting the amount of water entering the boezem during measurement. The more water that enters, the higher the total solid concentration. The lowest total solid concentration was on the fifth day of measurement because it was a national holiday. On public holidays or red dates, the tendency of water usage activities shifts to later hours so that water will reach the boezem inlet outside the measurement hours so that the total solid concentration measured during measurement is smaller.

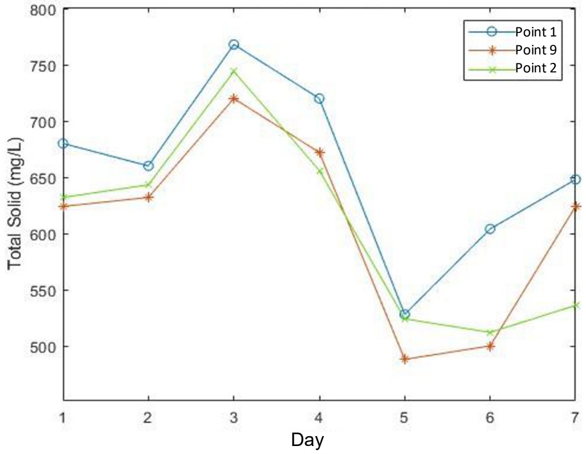


Figure 3. Total solid fluctuation.

On all seven days of measurement, the total solid concentration tends to decrease from the inlet towards the center of the boezem and increase from the center of the boezem towards the outlet. If the boezem functions as a stabilization pond, the total solid at the outlet should be lower than at the middle and inlet because the boezem has wastewater pretreatment capability. However, this is not the case in the Kalidami boezem case study due to the presence of illegal inputs from residents' activities in the form of domestic wastewater near the boezem outlet. When multiplied by the flow rate, the total solid load is obtained as follows

$$C = [TS] \times Q \tag{1}$$

Table 2. Total solid load

Sampling point	Total solid concentration ([TS]) mg/L	Flow rate (Q) L/s	Total solid load (C) mg/s	kg/s
1 (inlet)	658.2	1284	845231	0.845
9 (center)	608.5	613	373188	0.373
2 (outlet)	606.7	1284	779051	0.779

The total solid load decreases from the inlet to the boezem outlet. This is due to the concentration of total solid at the inlet is greater than in the center of the boezem and the outlet. In addition, the discharge at the three points is different, causing differences in the total solid load at the three points.

3.3. Flow Analysis of Transect Points

This flow analysis was used to predict the location of sediment deposition in the Kalidami boezem. The deposition velocity of boezem water was analyzed using a 1000 mL cylindrical tube and then observed at a depth of 0 cm to a depth of 10 cm. The settling time from a depth of 0 cm to 10 cm was calculated using a stopwatch. The calculation of settling velocity on the first day of measurement is as follows.

$$v = \frac{H}{t} \tag{2}$$

The average settling velocity (vs) value of 0.0091 m/sec is obtained as shown in **Table 3**.

Table 3. Average settling velocity

Measurement day	Dept (H)	Time (t)	Settling velocity (v_s)		Average settling velocity (v_s)
	cm	s	cm/s	m/s	m/s
1	10	9.99	1.001	0.01	0.0091
2		11.17	0.8953	0.009	
3		12.03	0.8313	0.0083	

The sedimentation velocity value is used as a reference for sedimentation at each transect point, which can be seen in **Table 4.** If the particle settling velocity (vs) is greater than the water flow velocity (vh), there will be settling of solid particles in the Kalidami boezem. The calculation of NRe flow is performed to determine the type of flow contained in the boezem. An example of NRe calculation at transect point 3 is as follows.

Flow velocity (vh) = 0,008 m/s
Hydraulic radius (R) = 2,61 m
Temperatur of boezem (T) = 30^0C
Kinematic viscosity (υ) = $0{,}8039\times10^{-6}\,\mathrm{m^2/s}$

$$NRe = \frac{Vh\ x\ R}{\upsilon} \tag{3}$$

$$= \frac{0{,}008\ \frac{\mathrm{m}}{\mathrm{s}}\ \mathrm{x}\ 2{,}61\ \mathrm{m}}{0{,}8039\ \mathrm{x}\ 10^{-6}\ \mathrm{m^2/s}}$$

$$= 24743$$

Table 4. NRe per transect

Sampling point	Flow velocity (vh) (m/s)	Average settling velocity (vs) (m/s)	Information	NRe
3	0.008	0.0091	Settled	24743.97
4	0.008		Settled	22837.87
5	0.008		Settled	14014.86
6	0.008		Settled	12297.40
7	0		Settled	0.00
8	0		Settled	0.00
9	0.008		Settled	18260.37
10	0		Settled	0.00
11	0.008		Settled	14168.74
12	0.008		Settled	16507.55
13	0.008		Settled	11421.30
14	0.008		Settled	13705.98
15	0.008		Settled	13395.61
16	0.008		Settled	14628.18
17	0.008		Settled	17754.20

All flows at the transect points are turbulent except transect 7, 8, 10. The NRe value at that point is 0 because the flow velocity is 0. This occurs due to the lack of accuracy of the current meter so that it is unable to read flow velocities of less than 0.03 m/s. The flow at most transects is turbulent. Turbulent flow can cause sedimentation but not all solids are fully sedimented. In addition, the flow at the transect is not always constantly turbulent so it is still possible for laminar flow to occur. The Reynold's number to achieve the best conditions in the sedimentation process is <2000 or under laminar conditions.

3.4. Analysis of Sludge Settling

Settling analysis using the Imhoff cone to determine the settling that occurs when associated with time. The settleable solids can be quantified in volume units, whereby the volume of precipitated substances is expressed in milliliters and divided by the volume of the sample. This analysis requires a sample of 1 liter, then placed on the imhoff cone and observed for 30 minutes.

Table 5. Sludge settling analysis

Measurement day	Volume of settleable solid (mL/L)			Average volume of settleable solid (mL/L)
	Point 1	Point 9	Point 2	
1	0	0	0.2	0.148
2	0.1	0.1	0.1	
3	0.3	0.1	0.7	
4	0.2	0.1	0.2	
5	0	0	0.1	
6	0.2	0.1	0.1	
7	0.1	0.1	0.2	
Average	**0.129**	**0.071**	**0.243**	

Sludge deposition occurred more at the outlet of Kalidami Boezem at point 2. This is probably due to the presence of small canals from the houses of the residents, where more waste disposal activities take place. In addition, there are coffee and food stalls near the outlet that discharge their wastewater into the boezem, which increases the influent load and increases the amount of sludge deposited at the outlet, although it does not have a significant effect. There is also algae at the outlet of the boezem, which has the potential to increase the volume of deposition. The sludge deposited in the center of the boezem is less in volume than at the inlet of the boezem. This can occur because the water flow velocity in the center of the boezem (point 9) is lower, so the solids have settled to the bottom of the boezem. The outflow at the inlet is greater than the outflow in the center of the boezem, so the silt that was originally deposited at the bottom becomes more turbulent and brings silt to the top of the water surface [7]. There is a very small volume of silt deposited, indicating almost no silt deposited or a value of 0. This probably happens in the field because the water flow in the boezem is calm so that the flowing solids do not experience turbulence [8].

3.5. Analysis of Sludge Degradation Rate

Sludge degradation rate was tested on three reactors representing three points, point 1 (inlet), point 9 (boezem center), and point 2 (outlet). Sludge weight weighing was carried out every day until the 25th day. To carry out the degradation rate analysis, the initial sludge weight (Co) and the specific time sludge weight (Ct) were calculated. In **Figure 4**, a descending line was obtained at all three *sampling* points indicating a decrease in sludge weight. This decrease in sludge weight is caused by microorganisms that decompose sludge organic matter into biogas which is a lot at the beginning and decreases over time [9]. Fresh sludge is rich in organic matter so organisms feed on the organic matter and turn it into gas. Microorganisms also experience lag and log phases, which means they need more organic matter to thrive. The most sludge reduction from a total of 25 days of observation occurred at point 1. This correlates with the highest *total volatile solid* content at point 1 so that the sludge is degraded the most at this point. Biogas produced by sludge degradation is directly proportional to the *volatile solid* content [10].

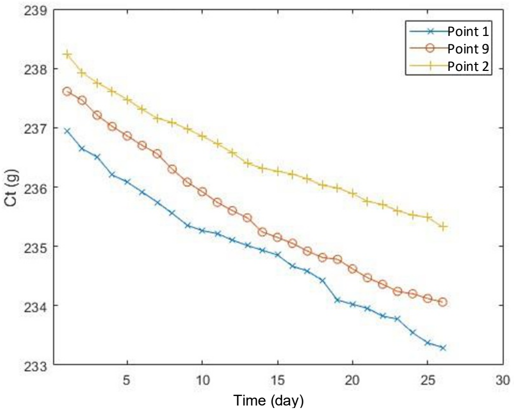


Figure 4. Sludge weight reduction graph.

In the 0th-order reaction, the experimental data results of the sludge degradation process were *plotting the* sludge weight (Ct) as the y-axis against time as the x-axis. If the sludge weight loss is averaged at the three points, a graph is obtained as shown in **Figure 5** which produces a value of R^2 = 0.9880. The R^2 value explains that the biodegradation reaction occurs following an order 0 reaction because the value is close to 1. The sludge weight loss occurs more slowly over time. This is because the activity of microorganisms in fresh sludge degrades the organic matter in the sludge faster. In contrast, sludge that has been deposited for a certain period of time will experience a decrease in degradation due to the death phase experienced by microorganisms due to the decrease in organic matter in the sludge as an energy source [11].

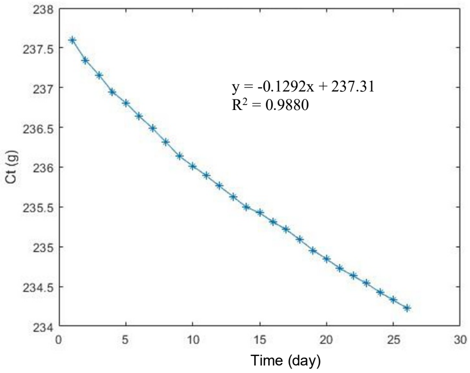


Figure 5. 0th order approximation graph

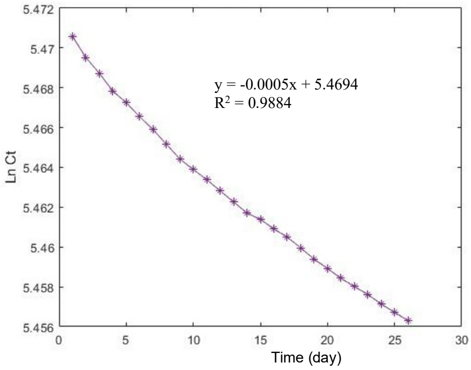


Figure 6. 1st order approximation graph

The first-order determination of the graph method is done by plotting the ln Ct value as the y-axis against time as the x-axis. The graph in **Figure 6** produces a value of R^2 = 0.9884. From the calculation results, the zero-order and first-order equation approaches have almost the same correlation coefficient (R^2) value. Comparison of correlation coefficient (R^2) values can be used to determine the order of reaction kinetics that corresponds to the degradation process. The R^2 value produced in the first-order graph is greater than that produced by the zero-order graph which indicates that the biodegradation reaction occurs following the first-order reaction because the value is closer to 1.

The equation in this study is the first-order reaction equation to calculate the degradation rate value of the Kalidami boezem sludge. This degradation rate value is used to predict the sludge mass reduction that occurs. The value of k is sought using the first-order equation from the graph as follows.

$$y = -0.0005x + 5.4694 \tag{4}$$

$x = 25 \rightarrow$ $y = -0.0005(25) + 5.4694$

$y = 5.4557$

$x = 0 \rightarrow$ $y = -0.0005(0) + 5.4694$

$y = 5.4694$

the value of slope (k)

$$k = \frac{\Delta_y}{\Delta_x} \tag{5}$$

$$k = \frac{y_{25} - y_0}{x_{25} - x_0}$$

$k = -0.0005/day$

The anaerobic degradation rate of Kalidami boezem sludge is 0.0005/day. The minus sign in the calculation indicates that there is a reduction or degradation of the amount of sludge.

3.6. Analysis of Sludge Accumulation

Sludge accumulation in the boezem can be estimated by summing up the difference between the *total solid* load at the inlet and outlet using the following formula.

$$Accumulation = [C_1 - C_2] - kCV \tag{6}$$

$$= 0.845\frac{kg}{s} - 0.779\frac{kg}{s}$$

$$= 0.066\frac{kg}{s}$$

$$= 5717.992\frac{kg}{day}$$

The results of sludge accumulation are still gross accumulation because it has not been reduced by the biodegradation process that occurs in the boezem sludge. When adjusted to the presence of anaerobic biodegradation in Kalidami boezem sludge, a first-order approach is taken because the Kalidami boezem sludge biodegradation process uses a first-order approach.

$$C_t = C \times e^{-kt} \tag{7}$$

$$= 658,286\frac{mg}{L}\ x\ e^{-0,0005/day \times 1\ day}$$

$$= 657,925\frac{mg}{L}$$

so

$$kC = C - C_t \tag{8}$$

$$= (658.286 - 657.925)\frac{mg}{L}$$

$$= 0.361\frac{mg}{L}$$

The sludge biodegradation result is 0.361 mg/L. This indicates that there is a reduction of 0.361 mg in every liter of Kalidami boezem sludge. To calculate the volume of sludge that enters and is deposited at the bottom of the Kalidami Boezem, it is necessary to multiply the volume of water by the volume of sludge obtained from the deposition analysis using the *Imhoff cone*. When multiplied by the time of day, the volume of water entering the Kalidami boezem is

$$V_{in} = Q_{in} \times t \tag{9}$$

$$= 1284 \frac{L}{s} \times 86400 \frac{s}{day}$$

$$= 111669911 \frac{L}{day}$$

The average volume of settled sludge obtained by the Imhoff cone method is 0.148 mL/L so that the volume of settled sludge in the volume of water entering the boezem is

$$V_{settleable\ sludge} = V_{in} \times V_{sludge\ imhoff\ cone} \tag{10}$$

$$= 111669911 \frac{L}{day} \times 0.148 \times 10^{-3} \frac{L}{L}$$

$$= 16527.147 \frac{L}{day}$$

The volume of sludge settling in a day based on the volume of water entering the boezem is 16527.147 L of sludge. Then the calculation of sludge accumulation rate in Kalidami Boezem on the basis of one day calculation is

$$Accumulation = bruto\ accumulation\text{-}kCV \tag{11}$$

$$= bruto\ accumulation - kCV_{settleable\ sludge}$$

$$= 5717.992 \frac{kg}{day} \text{-} (0.361 \times 10^{-6} \frac{kg}{L} \times 16527.147 \frac{L}{day})$$

$$= 5717.992 \frac{kg}{dayi} \text{-} 0.0059 \frac{kg}{day}$$

$$= 5717.986 \frac{kg}{day}$$

The volume of sludge produced due to sludge accumulation is calculated by dividing the accumulated sludge weight by the sludge density. The density of sludge from Kalidami boezem is 1156.132 kg/m³. Then the volume of sludge entering Kalidami boezem is

$$Sludge\ volume = \frac{net\ accumulation}{sludge\ density} \tag{12}$$

$$= \frac{5717.986\ kg/day}{1156.132\ kg/m^3}$$

$$= 4.946\ m^3/day$$

$$= 148.374\ m^3/month$$

$$= 1780.484\ m^3/year$$

Based on the above calculation, the sludge volume will fulfill the boezem capacity of 1780.484 m³/year. If it is known that the volume of Kalidami boezem is 108000m³. The sludge volume is compared to the boezem volume, so the percentage of sludge volume becomes

$$\%\ Sludge\ volume = \frac{settleable\ sludge\ volume}{volume\ of boezem} \times 100\% \tag{13}$$

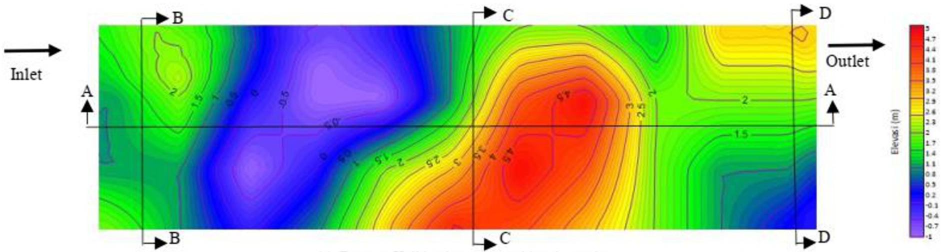
$$= \frac{1780.484\ m^3/year}{108.000\ m^3} \times 100\%$$

$$= 1{,}65\ \%$$

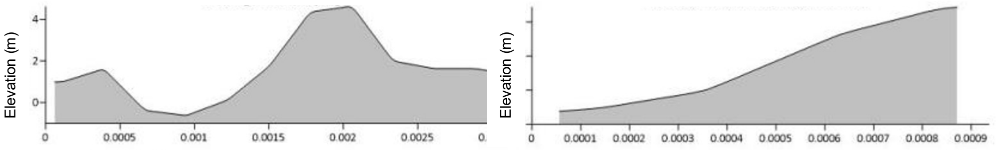
The sludge will fill the boezem area by approximately 1.65% of the effective volume of the boezem storage per year. The calculated sludge accumulation has not considered the compaction that occurs in the sludge at the bottom of the boezem. If compression occurs, the volume of sludge will decrease, resulting in higher sludge concentration. This causes the volume of sludge accumulated at the bottom of the boezem to decrease over time. Sedimentation brings nutrient-rich organic matter to the bottom of the boezem, where it is degraded by microorganisms. If the sedimentation rate is high, the sediment layer will be thick at the bottom of the boezem and reduce oxygen diffusion to the bottom. This increases the dominance of anaerobic degradation.

3.7. Analysis of Sediment Distribution Mapping

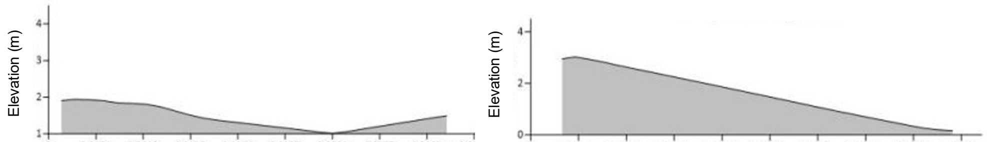
Mapping the distribution of sediments in the Kalidami boezem is based on differences in the concentration of *total suspended solid* spread at each transect point. Before mapping the sediment distribution, the initial contour of the Kalidami boezem must be known as the *baseline*. This contour can represent the height of mud/sediment at the bottom of the boezem based on satellite imagery. The deposition pattern of the Kalidami boezem can be categorized as a combination of *tapering deposits* and delta *deposits*. Tapering deposition patterns are common in long boezems where sediment settles less and less towards the outlet as can be seen in the A-A section in **Figure 7b**. For the delta deposition pattern, it can be seen in the middle of the southern boezem showing yellow to red colors in **Figure 7a**. This shows that the contour of the area is higher than the surrounding area which represents a pile or delta of sediment. The existence of this delta can be seen in the C-C cut in **Figure 7d** which shows a higher contour in the south.



(a) Boezem Kalidami countour with color scale



(b) Section A-A (d) Section C-C



(c) Section B-B (e) Section D-D

Figure 7. Contour section of Kalidami boezem.

Based on **Figure 7a**, the contours of the boezem vary from -1m to +5m above sea level. The lowest areas are colored purple and the highest areas are colored red. From the resulting contour map, longitudinal and transverse profiles of the Kalidami boezem can be obtained by cutting the existing contour map. Contours tend to be low at the inlet and get higher towards the outlet and then decrease again. When viewed from the deposition velocity which is greater than the boezem flow velocity, sediment should settle more in the inlet area. This can occur because the dredging carried out by the Surabaya City Water Resources and Bina

Marga Agency tends to be in the inlet area so that sediments deposited in the inlet are dredged. In addition, the water flow in the inlet area is a turbulent flow according to the NRe calculation in **Table 4** at *sampling* points 3, 4, and 5. This turbulent flow can cause solids not to settle completely in the inlet area due to turbulence so that unsedimented solids tend to settle in the center of the boezem, causing the contour in the center of the boezem to be higher.

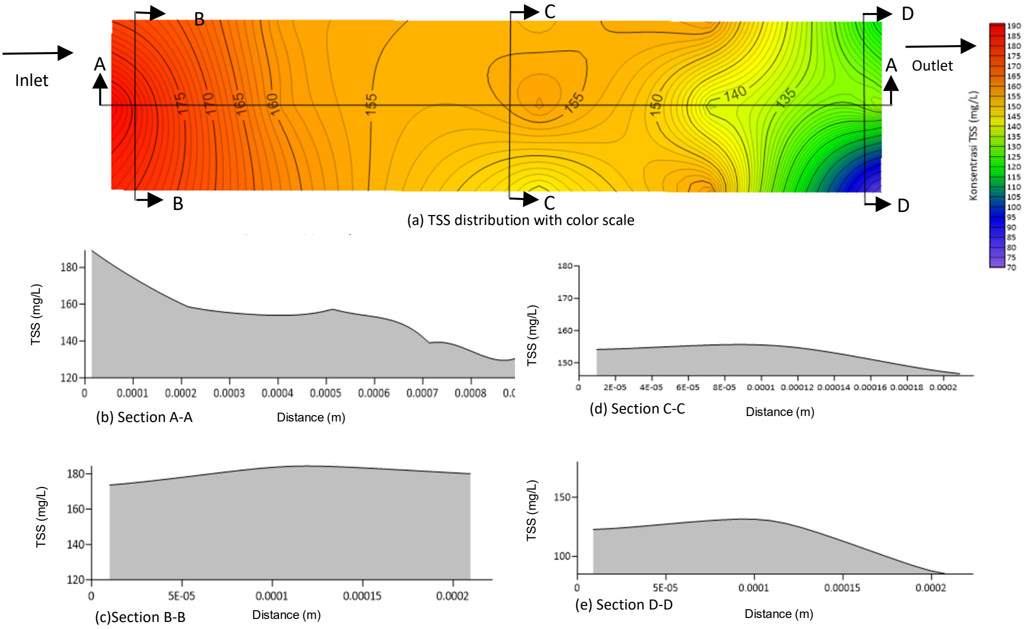
Contours formed by sediment accumulation at the bottom of the boezem can be a consideration for dredging locations. The distribution of sediment in the boezem can be seen from the decrease and increase in total suspended solids concentration, as TSS acts as the earliest sediment forming material [12]. TSS concentration can also reduce and affect the optical properties of water through absorption and scattering of sunlight, so it is positively correlated with water turbidity conditions [13]. The TSS range can be an indicator of sedimentation in a water body. Points with high TSS levels tend to have high sedimentation.

Table 6. TSS Concentration at Sediment Distribution Transect

Sampling point	TSS (mg/L)			Average TSS (mg/L)
	Day 1	Day 2	Day 3	
3	144	188	192	174.667
4	220	184	164	189.333
5	160	196	140	165.333
6	148	200	124	157.333
7	172	180	124	158.667
8	192	176	108	158.667
9	124	168	168	153.333
10	132	192	148	157.333
11	132	144	156	144
12	144	144	184	157.333
13	124	180	112	138.667
14	160	144	168	157.333
15	112	124	116	117.333
16	96	196	108	133.333
17	56	84	84	74.667

The area with the lowest TSS is colored purple and the area with the highest TSS is colored red. Based on **Figure 8b**, the TSS concentration is high at the inlet and decreases towards the outlet. This shows that sediment formation in the inlet area is higher than in the outlet area. Sedimentation is influenced by two things, namely solid content and flow type. Solid content describes the amount of solids contained in water.

The higher the solid content, the higher the settling velocity. This is due to the gravitational force that pulls solid particles down. Solid particles with higher solid content have a larger mass so that the gravitational force that pulls them down is also greater. Sedimentation is also affected by the type of flow. Sediment tends to settle at the inlet of the reservoir because the flow velocity is smaller than the settling velocity [14]. In addition, the decreasing TSS concentration from the inlet to the outlet can also be caused by the ability of the boezem as a wastewater pretreatment stabilization pond. In the cross-sectional profile of the boezem inlet (section B-B) in **Figure 8c**, the TSS concentration is low in the northern part of the cross-section and rises towards the center of the boezem then falls back in the southern part of the cross-section. The low TSS concentration could be due to the presence of water hyacinth and water spinach that grow wild at the edge of the boezem. This is also the case in the cross-sectional profile of the middle section of the boezem (section C-C) in **Figure 8d**.



(a) TSS distribution with color scale

(b) Section A-A

(d) Section C-C

(c)Section B-B

(e) Section D-D

Figure 8. Total suspended solid distribution.

The TSS concentration is high in the northern part of the cross section and the center then decreases in the southern part. This decrease in TSS concentration may be due to the presence of water hyacinth plants growing in the southern part of the boezem which reduce TSS levels. The cross-sectional profile of the boezem outlet (section D-D) in **Figure 8e** has a similar pattern to section C-C, where TSS concentrations are high in the north and middle of the cross-section and then decrease in the south of the cross-section. As discussed in the initial contours of the boezem, the lower TSS concentration in the southern part of the cross section may be due to pumping activities carried out by the Kalidami pump house operator. The suction power arising from the pump operation causes solids in the southern part of the cross section to be sucked up and carried to the sea. This results in lower TSS in the southern part of the cross section.

3.8. Dredging Recommendation

The determination of dredging location recommendations is based on an analysis of transect points exhibiting the highest sludge deposits. As illustrated in **Figure 7**, the initial contour of Kalidami boezem, exhibiting elevated terrain, is situated in the central portion of the boezem, encompassing transect points 9, 10, 11, 13, and 14. This region is demarcated by yellowish-orange areas. As illustrated in **Figure 8**, the point with the highest TSS concentration is situated in proximity to the inlet, towards the center of the boezem, and encompasses transect points 3, 4, 5, 6, 7, and 8, which are demarcated by orange areas. From these considerations, it is recommended that dredging be conducted at the inlet to the center of the boezem. If associated with the division of transects, dredging should be carried out at 12 transect points, starting from transect point number 3 to 14.

The sludge accumulation in the boezem is 1780.484 m^3/year or 148.374 m^3/month. If the dredging is based on the volume of sludge accumulated, the calculation of sludge dredging ritation needs can be done. In dredging the sludge, Surabaya City uses a truck with a capacity of 6 m^3 to carry the sludge. The dredging is planned to be done every 2 months because the optimum biogas formation in the anaerobic cycle in the stabilization pond occurs at a sludge residence time of 50 days [15]. The dredging time was increased to 60 days (2 months) to facilitate scheduling of dredging activities so that the volume of sludge per dredging was 296.747 m^3.

$$Ritation = \frac{volume\ of\ sludge\ per\ dredging}{capacity\ of\ truck} \tag{6}$$

$$= \frac{296.747\ \mathrm{m}^3}{6\ \mathrm{m}^3}$$

$$= 49.46 \text{ trips}$$

$$= 50 \text{ trips}$$

If accumulated per year, the number of trips required by sediment trucks is 600 trips. Sediment dredging in the boezems in Surabaya City in 2023 was carried out as many as 27 to 3981 trips per boezem. This shows that the planning of 600 ritations per year is still within the range of the ability of the Surabaya City Water Resources and Bina Marga Office to dredge sediment in the Kalidami boezem.

4. Conclusion

The anaerobic degradation rate in Kalidami boezem is 0.0005/day. The rate of sludge degradation is calculated using the first-order equation approach. The total sludge accumulation rate in Kalidami boezem is 1780.484 m^3/year, which represents 1.65% of the effective storage volume of the boezem. The distribution of Kalidami boezem sediment based on the concentration of total suspended solids exhibited a decrease from the inlet to the outlet. This phenomenon is attributable to the specific characteristics of the flow, as determined by Reynold's number, settling velocity, and flow velocity at each transect point. The settling velocity is greater than the water flow velocity, resulting in the deposition of a greater quantity of solids at the inlet of the boezem. Furthermore, the concentration of sediment decreases from the inlet to the outlet due to the implementation of dredging activities, which are predominantly conducted in the inlet area, and pumping operations at the Kalidami boezem pump house in the vicinity of the outlet.

Acknowledgement

This research was supported by funding from the Penelitian Departemen Batch 2 Tahun 2024, Institut Teknologi Sepuluh Nopember, under Research Contract No 2043/PKS/ITS/2024. We sincerely thank the Department of Environmental Engineering, ITS, for their valuable resources and guidance throughout the study.

References

[1] R. C. Afifah, P. S. Atmodjo, and S. Sri, “Unjuk Kerja Waduk Jatigede,” *Media Komun. Tek. Sipil*, **21**, 69–81, (2015). doi: https://doi.org/10.14710/mkts.v21i2.11232.

[2] S. Febrianto and N. Latifah, “Pemetaan Pola Sebaran Total Suspended Solid (TSS) Di Perairan Teluk Semarang Menggunakan Citra Satelit Landsat 7 Etm Dan Landsat 8,” *J. Harpodon Borneo*, **10**, 56–60, (2017). doi: 10.35334/harpodon.v10i1.202.

[3] R. Fitrianingtyas and A. Slamet, "Studi Pemetaan Persebaran Sedimen Boezem Morokrembangan," *J. Tek. ITS*, 7, 171–176, (2018). doi: 10.12962/j23373539.v7i1.28904.

[4] N. Manap and N. Voulvoulis, "Environmental management for dredging sediments - The requirement of developing nations," *J. Environ. Manage.*, 147, 1–11, (2014). doi: 10.1016/j.jenvman.2014.09.024.

[5] D. P. Satwika and B. V. Tangahu, Kajian Emisi Gas Rumah Kaca pada Upaya Penerapan Boezem Kalidami Sebagai Pretreatment Air Limbah Domestik di Surabaya, Bachelor Thesis, Institut Teknologi Sepuluh Nopember (2020)

[6] R. L. Sari, U. Lasminto, and N. F. Margini, "Perencanaan Jaringan Drainase Sub Sistem Kalidami Surabaya," *J. Hidroteknik*, 2, 28, (2017). doi: 10.12962/jh.v2i1.4399.

[7] R. A. S. Martini, Z. Bahri, and A. T. Miranda, "Pengaruh Debit Aliran Terhadap Sedimentasi Di Sungai Lematang Kabupaten Lahat," *Bear. J. Penelit. dan Kaji. Tek. Sipil*, **6**, 188–193, (2020). doi: 10.32502/jbearing.2841202063.

[8] M. Verbyla, M. von Sperling, and Y. Maiga, "Part Four. Management of Risk From Excreta And Wastewater," in *Waste Stabilization Ponds*, no. Water and Sanitation for the 21st Century: Health and Microbiological Aspects of Excreta and Wastewater Management (Global Water Pathogen Project)., UNESCO, (2017).

[9] V. K. Jensen, M. C. Cammarota, and I. Volschan, "Methane Production of Algal Biomass from Facultative Stabilization Pond: Evaluation of Anaerobic Biodegradability and Codigestion with Sewage Sludge," *J. Environ. Eng.*, 144, 1–7, (2018). doi: 10.1061/(asce)ee.1943-7870.0001359.

[10] E. K. Orhorhoro, P. O. Ebunilo, and G. E. Sadjere, "Experimental Determination of Effect of Total Solid (TS) and Volatile Solid (VS) on Biogas Yield," *Am. J. Mod. Energy*, 3, 131–135, (2017). doi: 10.11648/j.ajme.20170306.13.

[11] R. O. Khastini, L. R. Zahranie, R. A. Rozma, and Y. A. Saputri, "Review : Peranan Bakteri Pendegradasi Senyawa Pencemar Lingkungan melalui Proses Bioremediasi," *Biosci. J. Ilm. Biol.*, 10, 345–360, (2022). doi: 10.33394/bioscientist.v10i1.4836.

[12] M. Yonar, O. M. Luthfi, and A. Isdianto, "Dinamika Total Suspended Solid (TSS) di Sekitar Terumbu Karang Pantai Damas, Trenggalek," *J. Mar. Coast. Sci.*, **10**, 48–57, (2021).

[13] X. Hou, L. Feng, H. Duan, X. Chen, D. Sun, and K. Shi, "Fifteen-year monitoring of the turbidity dynamics in large lakes and reservoirs in the middle and lower basin of the Yangtze River, China," *Remote Sens. Environ.*, 190, 107–121, (2017). doi: 10.1016/j.rse.2016.12.006.

[14] G. W. Annandale, L. M. Gregory, and K. Pravin, *Extending the Life of Reservoir: Sustainable Sediment Management of Dams and Run-of-river Hydropower*. World Bank Group, 2016. doi: doi.org/10.1596/978-1-4648-0838-8.

[15] T. Z. D. de Mes, A. J. M. Stams, J. H. Reith, and G. Zeeman, "Methane production by anaerobic digestion of wastewater and solid wastes," in *Bio-methane & Bio-hydrogen*, (Dutch Biological Hydrogen Foundation, 2003).