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Flow Engineering to Remediate Contaminated Water Quality Due to Domestic Waste Disposal in Belik River, Yogyakarta

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ABSTRACT

The Belik River Basin is located in an urban area and is affected by rapid population growth. Belik River flows from north of the UGM campus (Karangwuni Subvillage in Caturtunggal, Depok, Sleman) to Umbulharjo District then feeds into Gajah wong River before emptying into Opak River. This study sought to examine the effects of flow engineering on the quality of domestic waste-contaminated waters. The flow engineering is in the form of a small weir or pile of stones aiming to elevate the upstream water level and create a free fall or plunge that aerates the overflowing water. The water was sampled from four river segments twice: upstream and downstream of the designed weir. Water sampling from one element to the next factored in water travel time and settlement density in the surroundings with the assumption that these factors would produce different concentrations of domestic waste. The water quality parameters tested were D.O., BOD, COD, phosphate, nitrate, ammonia, and iron. The results showed that the flow engineering improved water quality in the four segments differently, as evident from some of the decreased or increased parameter values after the plunge. These different effects are influenced by the number of sources of domestic waste pollutants and the dominant land use in each segment.

INTRODUCTION

Population growth is a significant issue that is fundamental and multifaceted. It drives an increase in basic human needs like food and space for housing (Safitri & Effendi, 2019). Population growth always co-occurs with economic growth because it tends to trigger the conversion of originally non-residential lands that are productive or serve as ecological conservation into residential areas (Suprayogi & Isa, 2019). Increasing economic development activities, land-use change, and population growth rates have created high environmental pressures (Surya et al., 2020).

To meet their life needs, humans perform and engage in various activities. Domestic and agricultural sectors produce waste that contributes to declining river water quality (Arnop et al., 2019; Wahyuningsih et al., 2020). Domestic waste causes many environmental, health, and aesthetics (Hasibuan, 2016). Dissolved oxygen (D.O.) plays an essential role as a water quality indicator that determines the river's self-purification ability (Junaidi et al., 2021). The rates of deoxygenation and reaeration influence changes in D.O. concentrations. Deoxygenation occurs when bacteria use dissolved oxygen to decompose organic matters, while reaeration introduces oxygenated air into waters by turbulence (Vandra et al., 2016; Yustiani et al., 2018). As part of the environment, many rivers are in poor conditions and prone to ecological changes indicated by degrading water quantity and quality (Suprayogi, Marfai, et al., 2019).

The city of Yogyakarta has experienced relatively rapid growth in the last ten years. One of them is the change in land use dominated by housing and office buildings. It has increased by 1.44 Ha in the previous period, and the reduction in the vegetated area has reached 23.47 Ha (Suprayogi, Marfai, et al., 2019). It includes the construction and procurement of infrastructure to evenly distribute urban facilities that continue to expand with the city's development. The town's growth and its surrounding districts form an agglomeration termed Yogyakarta Urban Agglomeration (YUA). Newly constructed roads that connect several activity centers show that the city has developed according to the spatial planning concept. A characteristic of regional physical development is more land transforming into built-up areas (Suprayogi, 2017).

Belik River Basin is located in an urban region. The river flows from the Karangwuni area where the Universitas Gadjah Mada (UGM) campus is located to the south through densely populated areas. Along with the increasing population growth rate in the river basin (mainly through immigration), domestic waste disposal in the neighborhood increases. This condition will undoubtedly intensify the pressures on aquatic environments (Suprayogi, Fatchuroman, et al., 2019).

Domestic waste that enters the Belik River in the north is carried to the water park in Lembah UGM, while the one in the middle flows into Langensari Reservoir. Water that transports domestic waste into the reservoir does not flow directly downstream. Instead, it remains in the structure for a while and undergoes filtration and sedimentation as parts of self-purification (Suprayogi, Marfai, et al., 2019).

The reasons for this research are the problems in previous studies that explain the amount of domestic waste and the increase in water quality in the Belik watershed. This study has applied flow engineering on four river segments by constructing small weirs or piles of stones to create a free fall or small weir stream from the overflowing water. This technique induces aeration that will increase dissolved oxygen and remediate water quality in the segment (Akhlaque et al., 2017). This study aimed to examine the effects of flow engineering on water quality in a river contaminated with domestic waste.

RESEARCH METHOD

Data and Tools

This research observed the effects of the designed small weirs on water quality directly in the field. During which, water velocity data at the sampling location was also collected. The tools used in this research are presented in Table 1.

Table 1. The tools used in this research

No	Tools	Function
1	GPS	Positioning location sampling water
2	Abney Level	Measure riverbed slope
3	Measuring tapes and roads	Measure length and width river section
4	Sample bottles	Collect water samples to water quality test
5	camera	Take pictures
6	Computer	Processing data
7	Stationary	List and process data
8	Laboratory tools	Test the water quality

The research framework is presented in Figure 1.

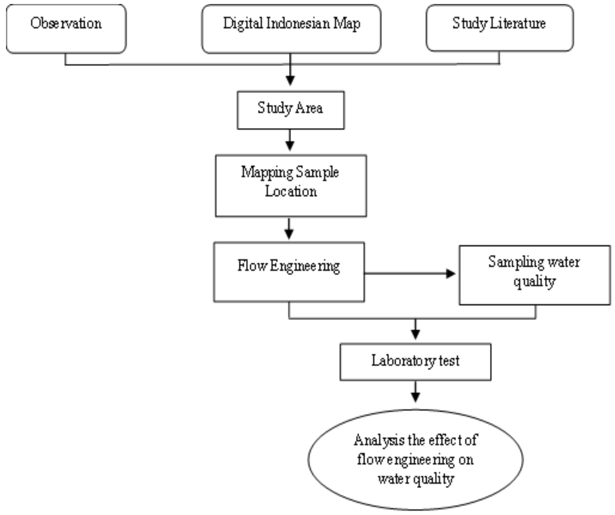

Figure 1. Research framework

Water Sampling

The location of collect water sampling is presented in Figure 2.

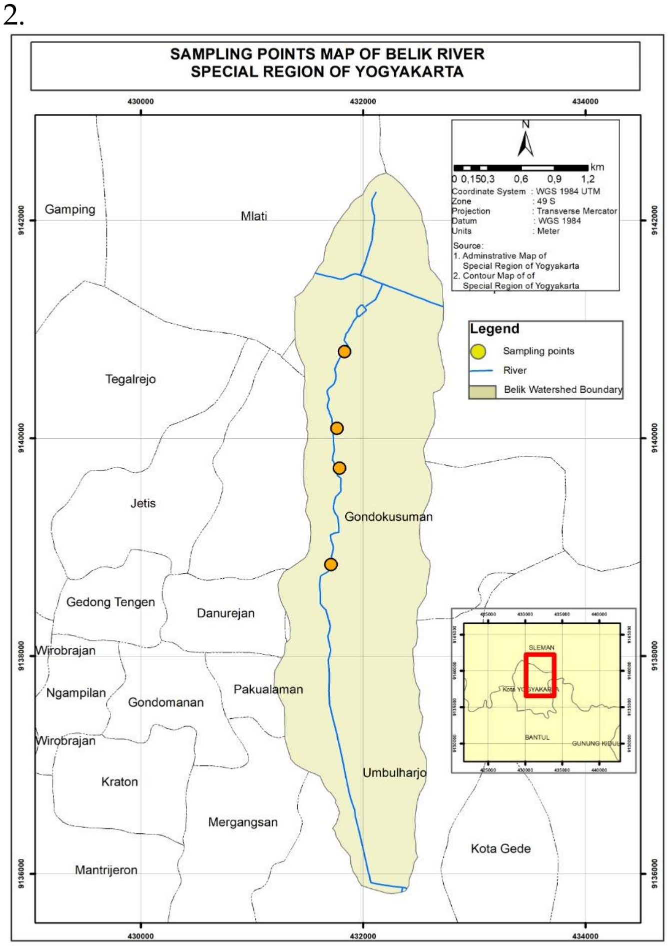

Figure 2. Map of sampling point

The river was first divided into segments according to settlement density in the surroundings, if each density would generate domestic waste in a different concentration. Water sampling from one element to the next factored in water travel time. It is the distance between two sampling points divided by water velocity or as written in the equation below with Manning formula modified by (Chow, 1959; McKay & Fischenich, 2011).

$$T=\frac{L}{V}$$

T = water travel time (minutes)
L = distance from point 1 to point 2 (m)
V = water velocity (m/s)
As for the water velocity, it was calculated in each segment using the equation below:

$$V = \frac{1}{n} x\, R^{\frac{2}{3}} x\, S^{\frac{2}{3}}$$

V = water velocity (m/s)
R = hydraulic radius (R = A/p),
A =wet cross-sectional area (m^2)
p = wet perimeter (m)
S = riverbed slope

Water samples were collected upstream and downstream of the weir. This sampling technique assumes that the structure aerates water as it overflows, thus remediating the water quality. At the weir's edge, waterfalls freely then form hydraulic jumps downstream. According to Achmad (2014), there are four types of hydraulic jumps: weak, oscillating, steady, and strong (Figure 3).

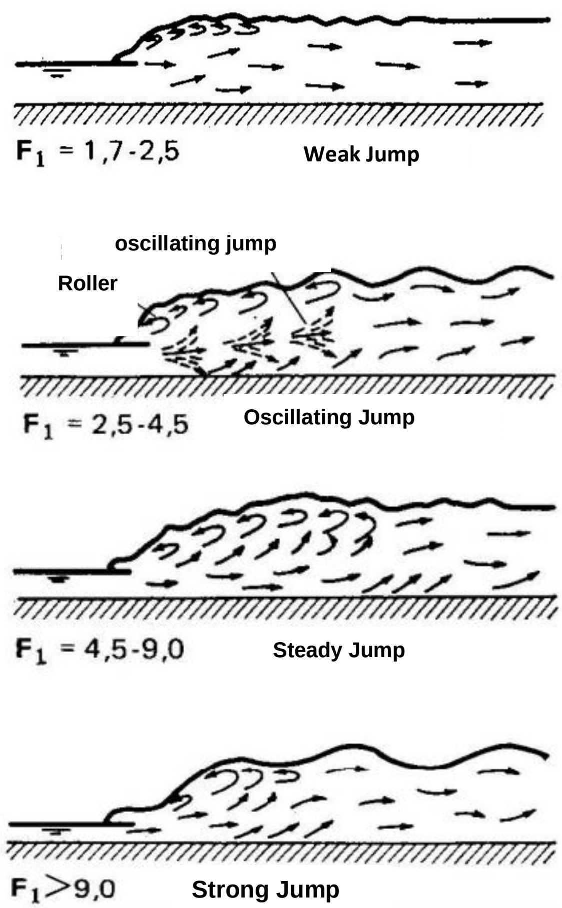

Figure 3. Hydraulic jumps after free falls or plunges (Source: Achmad, 2014)

Water Quality Parameter Analysis

The chemical parameters analyzed were dissolved oxygen (D.O.), biochemical oxygen demand (BOD), chemical oxygen demand (COD), phosphate (PO_4), nitrate (NO_3), ammonia (NH_3), and iron (Fe); all of which indicates the presence or effects of domestic waste in the water.

RESULTS AND DISCUSSION

Belik River flows from north of the UGM campus (Karangwuni Subvillage in Caturtunggal, Depok, Sleman) to Umbulharjo District then feeds into Gajahwong River before emptying into Opak River. Anthropogenic influences are evident from the surrounding land use. Human activities that utilize the natural environment, namely land, to meet particular needs are called land use (Ritohardoto, 2009). Continuous entries of domestic waste from residential areas and other land uses into the river can contaminate and accumulate water pollutants (Kerstens et al., 2013). For these reasons, it is necessary to analyze the water quality in the Belik River and use a flow engineering technique, small weirs, to remediate water quality.

Water quality data were analyzed and evaluated from the samples collected in four river segments. Each segment has two models: upstream and downstream of the weir. The spatial distribution of the water quality parameters in the Belik River is presented in Figure 4.

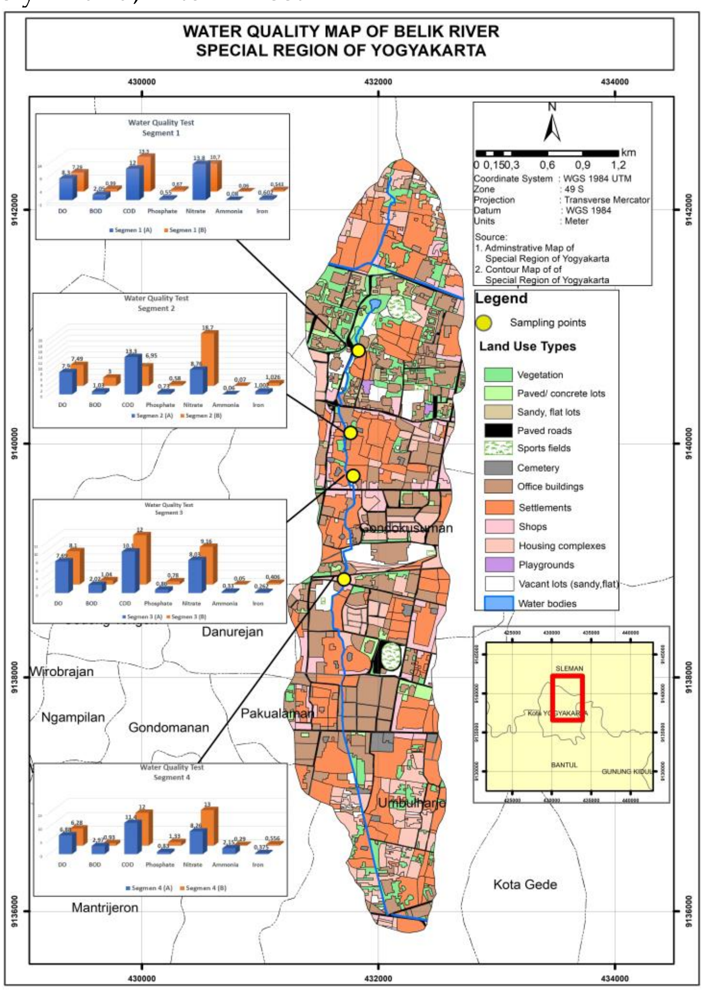

Figure 4. Water quality map of Belik River

Based on figure 3, the surrounding areas were mainly used for settlement office areas. This indicates that increased human activities can affect river water quality. The analysis of the water quality of the Belik River for each segment is as follows.

Segment 1

This segment's sampling points are located near Stella Duce Dormitory in Samirono, Yogyakarta City. Table 1 shows the laboratory test results of the water quality parameters for segment 1, upstream (A), and downstream (B) of the designed weir.

There are differences in parameter values between the two samples. Some showed improvements after the plunge, namely BOD, nitrate, ammonia, and iron. COD was much higher than BOD, usually caused by organic matter that decomposes chemically rather than biologically (Yohanes et al., 2014). Although the downstream COD in this segment was higher, it still met the water quality standard listed in Government Regulation Number 22 of 2021.

Table 2. Water quality analysis results in segment 1 upstream and downstream of the designed weir

Parameters	Samirono sub village	
	A	B
DO	8.3	7.29
BOD	2.05	0.99
COD	12	13.3
Phosphate ($PO4^{3-}$)	0.55	0.67
Nitrate (NO^{3-})	13.8	10.7
Ammonia (NH_3)	0.08	0.06
Iron (Fe)	0.602	0.543

Source: Data analysis results, 2021.

After a small weir, the water in segment 1 contained smaller amounts of nitrate. The presence of nitrate compounds in waters depends on two factors: deficient dissolved oxygen levels and denitrification by nitrifying bacteria (Sumantri & Cordova, 2011). High nitrate concentrations are associated with anthropogenic wastes from domestic activities, livestock waste, and excessive use of organic fertilizers (Suprayogi, Marfai, et al., 2019).

Similarly, ammonia and iron levels decreased after overflowing the designed weir, but an increase in phosphate was detected. Nevertheless, these three parameters were higher than two mg/L in upstream and downstream water samples, exceeding their maximum allowable presence in waters suitable for class II purposes, e.g., water recreation, agricultural irrigation, livestock farming, and freshwater aquaculture. The high phosphate indicates contamination by organic and inorganic domestic wastes and detergents in the segment (Larasati et al., 2021).

The D.O. levels upstream and downstream of the weir were categorically good, > 4 mg/L. The higher the amount of dissolved oxygen, the better the water quality (Prahutama, 2013). On the contrary, low D.O. indicates pollution. D.O. levels in waters are generally in the range of 5.7–8.5 mg/L (Simon, 2015). After the plunge, there was a slight decrease in the D.O. level in this segment.

Segment 2

The sampling points in the second segment are located at Lembah UGM Park. Based on the water quality analysis results presented in Table 2, there are differences in parameter values between the water samples collected upstream (A) and downstream (B) of the weir. The upstream sample contained much lower COD and phosphate but higher BOD, D.O., nitrate, ammonia, and iron than the downstream sample. The last five parameters remained high because the surrounding areas were mainly used for settlements, a primary source of domestic waste (Abdel-shafy & Mansour, 2018). Some of the pollutants contained in domestic waste include pathogenic microorganisms, sediments, substances, nutrients, organic and inorganic (Dharmawan et al., 2020). Settlement areas with many people affect the environment, especially river flow. Domestic waste will contaminate the river and destroy the ecosystem and quality of the river.

Table 3. Water quality analysis results in segment 2 upstream and downstream of the designed weir in lembah UGM park

Parameters	Lembah UGM Park	
	A	B
DO	7.9	7.49
BOD	1.03	3
COD	13.3	6.95
Phosphate ($PO4^{3-}$)	0.73	0.58
Nitrate (NO^{3-})	8.76	18.7
Ammonia (NH_3)	0.06	0.07
Iron (Fe)	1.002	1.026

Source: Data analysis results, 2021.

Segment 3

The sampling points for the third segment are located nearby Langensari Reservoir. Table 4 compares the water quality analysis results at points A (upstream of the designed weir) and B (downstream). Again, the two samples showed differences in parameter values, with D.O., BOD, phosphate, and ammonia showing improvements after the plunge. The higher D.O. levels indicate that the engineering technique induces an aeration process that introduces oxygenated air into the water (Dharmawan et al., 2020). Based on Government Regulation Number 22 of 2021, the upper limit value for ammonia presence in waters for class II purposes is 0.2 mg/L. Accordingly, there is a significant change in the ammonia content before and after the plunge, from 0.33 mg/L (exceeding the upper limit value) to 0.05 mg/L (below the upper limit value). In rivers, ammonia usually comes from the byproducts of aquaculture and the decomposition of organic matter (Makmur et al., 2012).

Table 4. Water quality analysis results in segment 3 upstream and downstream of the designed weir in Langensari Reservoir

Parameters	Langensari Reservoir	
	A	B
DO	7.69	8.1
BOD	2.02	1.04
COD	10.1	12
Phosphate ($PO4^{3-}$)	0.86	0.78
Nitrate (NO^{3-})	8.03	9.16
Ammonia (NH_3)	0.33	0.05
Iron (Fe)	0.262	0.406

Source: Data analysis results, 2021.

The downstream sample contained higher COD, nitrate, and iron. However, based on Government Regulation Number 22 of 2021, these values are still below their upper limits for class II waters (COD, nitrate <20 mg/L). Nitrogen in domestic waste significantly influences nitrate content in water bodies (Patricia et al., 2018), especially in the river segment where settlements and housing complexes occupy most of the surrounding area.

Segment 4

Sampling points in the fourth segment are in the Baciro area. Table 5 compares the water quality analysis results of the samples collected upstream (A) and downstream (B) of the designed weir. The two models showed different values for all parameters.

Table 5. Water quality analysis results in segment 4 upstream and downstream of the designed weir in Baciro

Parameters	Baciro	
	A	B
DO	6.88	6.28
BOD	2.97	0.93
COD	11.4	12
Phosphate ($PO4^{3-}$)	0.83	1.33
Nitrate (NO^{3-})	8.26	13
Ammonia (NH_3)	2.15	0.29
Iron (Fe)	0.375	0.556

Source: Data analysis results, 2021.

BOD and ammonia contents were lower in the downstream sample, indicating that the flow engineering technique remediates contaminated waters. According to Government Regulation Number 22 of 2021, the upper limit value of ammonia in waters suitable for class II purposes is 0.2 mg/L. Although the ammonia levels at the sampling points were higher than the upper limit, they significantly decreased from 2.15 to 0.29 mg/L. After the plunge, the D.O. levels fell by 0.6 mg/L. As the water in the first segment, the COD was higher than BOD, indicating a dominant chemical decomposition of organic matter than biological decomposition (Hur & Cho, 2012). The organic topics in this segment are from human activity. Heavy settlement contaminated the river with nitrogen, phosphorus, phenol, detergent, and *E. Coli* (Vavillin et al., 2008). The activities which contribute to domestic waste are dominated by washing, bathing, and using lavatory (Prilly et al., 2019).

CONCLUSIONS

Based on the analysis results in Belik River, the flow engineering has remediated the water quality in each segment to different extents. The effects include decreased BOD, ammonia, iron, and nitrate contents in segment one and COD and phosphate in segment 2. In segment 3, when the upstream water overflows the designed weir, the small weir stream reduces the BOD and phosphate contents but increases the D.O. levels because of aeration. Meanwhile, in segment 4, the flow engineering effectively decreases BOD and ammonia concentrations in the water. These varying effects are associated with the fluctuating parameter values in the river, which depend on the number of sources of domestic waste pollutants and the dominant land use in each segment. The flow engineering is in the form of a small weir or pile of stones that can be used to improve water quality. Still, it is necessary to socialize the community about domestic waste disposal and regulations of land-use change around the river.

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