

Design and modification of horizontal-flow roughing filter as water treatment at UGM retention pond

Niesa Hanum Mistoro^{1,*} and Sri Puji Saraswati¹

¹Department of Civil and Environmental Engineering, Faculty of Engineering, Universitas Gadjah Mada, Indonesia

Abstract. UGM Retention Pond as flood controller has its water supply from Belik River. Based on water quality monitoring results by the Environment Agency (BLH) of DIY in 2012–2016, the water status at the upstream area of Belik river has already contaminated before it flows to the retention pond. This study aims to make UGM Retention Pond not only as flood control, but also as a water treatment. The function can be fulfilled with the innovation of rough filter water type applied to horizontal flow, i.e. Horizontal-flow Roughing Filter. Mass balance analysis on the retention pond was calculated based on the assumption of the pond as a complete-mix reactor with BOD₅ of 20.9 mg/L and TSS of 102 mg/L with discharge (Q) of 2.54 m³/s. The maximum target output produced for BOD₅ was 3 mg/L and TSS was 50 mg/L so the target of filtering efficiency was 94 %. The analysis results showed the most optimal Horizontal-flow Roughing Filter was elongated beam-shaped design with length dimensions of 44.6 m, width of 2.5 m, and height of 1.7 m. Filter media used in the form of pebble (gravel) with the size of 24–16 mm and assumed to have permeability coefficient $k = 0.1$ m/s.

1 Introduction

UGM Retention Pond is built as a facility to collect rainwater and prevent frequent flooding in the downstream area of Belik River. Belik River flows through dense settlements that mostly dispose their domestic wastewater directly into the river. As the area is located near UGM campus, thus there are many constructions of homestays, laundry services, and restaurants. The various activities occurring in the surrounding areas give various types of pollutants that flow back into the Belik River, and produce a lot of domestic wastewater which can adversely affect the water quality. Moreover, there is no water treatment to process before it flows to the river. The river is polluted due to wastewater that exceeds the river capacity. Therefore, the water from Belik River that was flown into UGM Retention Pond is also polluted. The number of residents around the downstream area of Belik River state that water will overflows during heavy rains, and the water is still polluted after passing through the UGM area. Thus, UGM Retention Pond has only functioned as a flood controller when it can also function as water-treatment. This research designs water filter innovations that can be applied to the pond. Horizontal-flow Roughing Filter is a coarse-type water filter innovation for horizontal flow. The filter media is gravel in several sizes. It is expected that UGM Retention Pond can function as flood control and water treatment.

2 Horizontal-flow roughing filter

Horizontal-flow Roughing Filter (HRF) is a type of rough filter for horizontal flow direction. Variable Design of Horizontal-flow Roughing Filter are:

Media type and size of the filter

Filter media types that are commonly used are sand, quartz, and gravel, but it can also be replaced with any material that has the characteristics of clean, not soluble, and mechanical [1]. The increase of filtering efficiency corresponds to the smaller size of filter media. In the multiple layers design, the size of the filter media is reduced each layer according to the flow direction [2].

Table 1. Size of gravel used in HRF.

Description of coarse filter	First layer (mm)	Second layer (mm)	Third layer (mm)
Coarse	24–16	18–12	12–8
Normal	18–12	12–8	8–4
Fine	12–8	8–4	4–2

Filtration rate

An effective screening process on HRF can be achieved with a low filtration rate because it is important to keep particles from settling to the bottom of the filter media. Wegelin suggested filtration rates for filter operations should be ranging from 0.3–2 m/hr [3,4].

*Corresponding author: niesa.hanum.m@mail.ugm.ac.id

Hydraulic retention time

The increase of filtering efficiency corresponds to the slow rate of hydraulic loading in the laminar stream. The flow conditions can be described by Reynolds number [5].

Filter length

The filter length can increase the cumulative filtration efficiency by increasing the filter length dimension. Differences in filter media size in multiple HRF layers will be more effective to achieve filtering targets although it has shorter filter length dimensions, rather than uniformly sized filter media in one layer with longer length dimensions [6].

2.1 Calculation of horizontal-flow roughing filter design

Generally, shallow/short buildings have no structural problems. The filter length depends on the turbidity of the incoming water source and the range is between 5 to 7 m [7]. Drainage facilities, such as perforated pipes and culverts make a clean filter bottom. This drainage system is placed under a filter perpendicular to the flow direction. A complete calculation to determine the design of HRF can be seen in Figure 1.

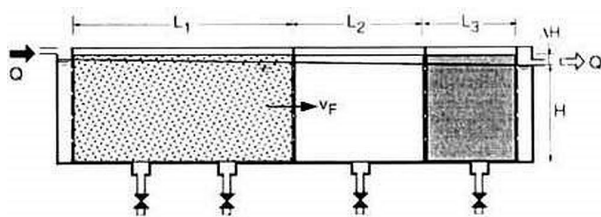


Fig. 1. Layout and design of HRF [4].

Figure detail:

- d_g = gravel's size (mm)
- H = filter depth (m)
- $L_{1,2,3}$ = filter length (m)
- W = filter width (m)
- A = wetted perimeter (m^2)
- ΔH = maximum headloss, 30 cm
- Q = flow debit (m^3/hr)
- Q_d = drainage debit (m^3/hr)
- v_F = filtration rate (m/hr)
- v_d = drainage rate (m/hr)

Horizontal-flow Roughing Filter dimension is calculated with the following equation:

$$v_F = \frac{Q}{H \cdot W} = \frac{Q}{A} = 0,3 - 2 \text{ m/hr} \quad (1)$$

$$v_d = \frac{Q_d}{(L_1 + L_2 + L_3) \cdot W} = 60 - 90 \text{ m/hr} \quad (2)$$

The equation above to calculate the filtration rate Horizontal-flow Roughing Filter, by knowing the requirements of the two equations can be calculated the HRF dimension.

3 Methods

The research was conducted at UGM Retention Pond which is located in Wisdom Park UGM area, as seen in Figure 2.

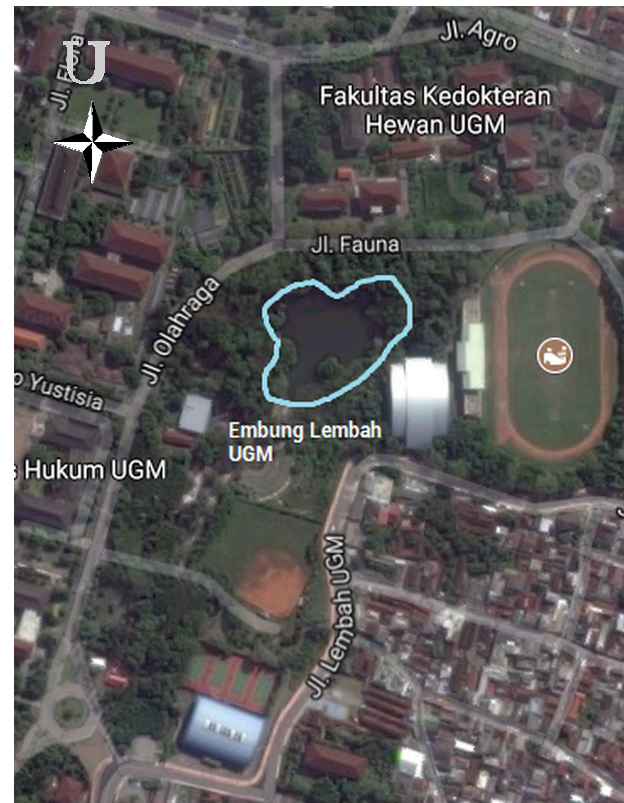


Fig. 2. Location of UGM Retention Pond.

UGM Retention Pond serves as a rainwater container and flood controller with Retention Pool type beside the river. The description of UGM Retention Pond shape can be seen in the pond technical data in Table 2.

Table 2. Technical data of UGM Retention Pond.

Description	Size	Unit
Elevation of inlet gate	131.9	m
Elevation of outlet gate	129.25	m
Pond volume	7000	m^3
Elevation of pond's maximum water surface	130.7	m
Elevation of pond's bed	129	m

At the design stage of Horizontal-flow Roughing Filter (HRF), the placement in the pond need to be determined in order to produce optimal efficiency. The HRF was placed in 3 zones that can be used as the limits of alternative design proposal calculations. The three zones were:

1. Zone I, pond's input channel, when the Belik river discharge is divided into two flows, to Belik River and to the pond has input channel.
2. Zone II, UGM Retention Pond.
3. Zone III, pond's output channel, when water flow out from the pond and back to Belik river.

These zones can be seen in Figure 3.

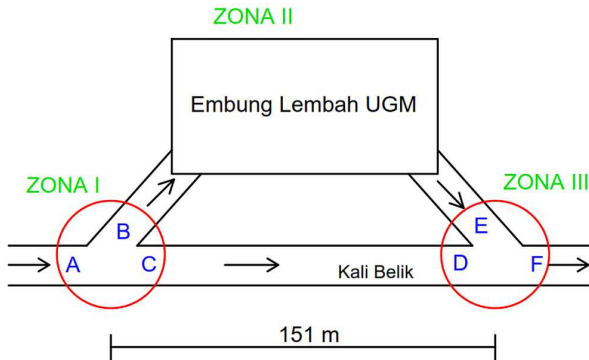


Fig. 3. HRF design zoning.

Stage Design of Horizontal-flow Roughing Filter:

1. Determination of HRF design location, from three zones, the HRF design variable is conducted by checking filtration rate to know the zone that is qualified for HRF installation.
2. Determination of filter media, in the selection process of material, the most important factor is the material permeability coefficient.
3. Calculation of HRF design, Horizontal-flow Roughing Filter design is calculated with Wegelin guideline, 1996. First step, calculate the mass balance of pond before prior to filtration with the assumption of pond as a complete-mix reactor, the water quality value of BOD₅ and TSS as the HRF design variable. The, calculated the design efficiency by determining BOD₅ and TSS filtering results according to water quality standard of PP DIY No. 7 of 2016. HRF calculations use the assumption of a packed-bed reactor mass balance.
4. Calculation of wiremesh requirement, the HRF used in the form of wiremesh and galvanis.
5. Operation and maintenance, conducting literature studies to find out its operational and maintenance.

4 Results

4.1 Design layout analysis

One of the HRF design variables, in order to have optimum operational, is the filtration rate. The filtration rate value required in the design normally ranged from 0.3–2 m/hr to reduce the turbulence which can reduce filter efficiency. The HRF possible location in three zones was conducted by calculating each filtration rate. The formula for filtration rate calculation is determined by Wegelin [3], as follows the Equation 1.

The result of a flow rate input channel of the pond is far from the design criteria of HRF (0.3–2 m/h), it is 835.91 m/h which means the flow along the input

channel is too fast and HRF design cannot be put in the location. The calculation of Bernoulli equation determines the total head (h). The result show $h = -4.89 \times 10^3$ m that it cannot be applied in the input channel of the HRF placement location.

The result of flow rate output channel of pond is far from the design criteria of HRF (0.3–2 m/h), it is 194.53 m/h, which means the flow along the output channel is too fast and HRF design cannot be put in the location. The calculation of Bernoulli equation determines the total head (h). The result show $h = -1.20 \times 10^4$ m that it cannot be applied in the input channel of the HRF placement location too.

A large filtration rate can cause the deep penetration of coarse particles into the bottom of filter and this can reduce filtering efficiency. Furthermore, large filtration rates can cause the grinding of filter materials and the imbalance flow can reduce overall filtering efficiency [6]. Thus, the Horizontal-flow Roughing Filter can possibly be placed inside the UGM Retention Pond.

4.1.1 Determination of HRF location with continuity principle approach

From the analysis of filtration rate, it can be known that location for Horizontal-flow Roughing Filter is inside the pond. In order to find out the exact position of HRF, the calculation is conducted with the principle of continuity approach, using the maximum debit data in BLH DIY data of 2012–2016 i.e. in February 2012 of 2.54 m³/s [10].

The Horizontal-flow Roughing Filter position shall be placed inside the pond which has a flow rate of filtration rate of 0.3–2 m/hr. It was also expected that no runoff passes through the design peak surface. With the principle of continuity, the fluid flow scheme is shown in Figure 4. The scheme requires volume calculation at Zone A, in condition, there is no interference with the filter during its operational. It means the discharge that fills the area has the same speed as the filter filtration rate. The following calculation determines the volume of Zone A, with $Q_{\max}$ as the inlet maximum discharge = 2.54 m³/s, Q_A as the discharge of zone A, A_A as the surface area of zone A, V_{filter} as the filtration rate, $h_{\max}$ as the maximum height of pond, and the V_A is the volume of zone A:

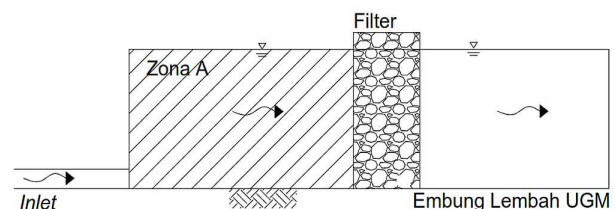


Fig. 4. Continuity approach scheme.

The volume of zone A that not disturb filter operation equals to 692.72 m³, and the best location for Horizontal-flow Roughing Filter at Zone A is in the middle of the pond with a filter width of 44.6 m.

Description of Horizontal-flow Roughing Filter design layout in UGM Retention Pond can be seen in Figure 5.

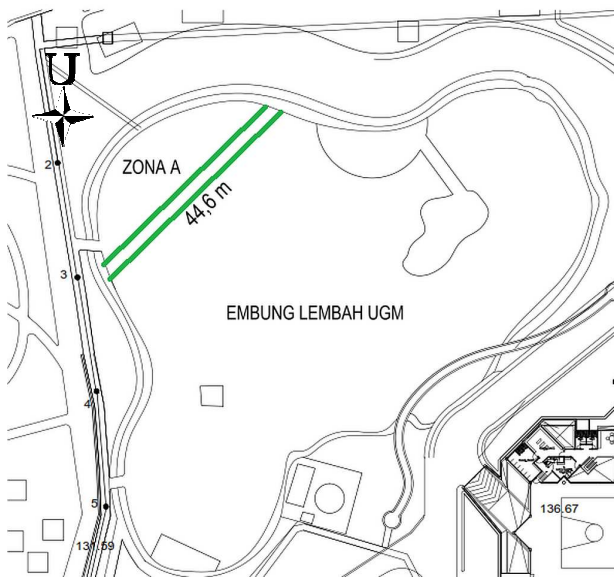


Fig 5. Location of Horizontal-flow Roughing Filter design.

4.1.2 Filter media

Filter media used in this research is gravels, considering that some research of Horizontal-flow Roughing Filter used materials other than gravel, but the results given are no better than gravels. This happens because filtering is closely related to filter permeability coefficient value and the greater the permeability coefficient, the greater filtering efficiency.

The permeability coefficients of the proposed gravel need to be tested its material permeability, but due to insufficient time then it used the assumption of the common permeability of gravel or gravel coefficient ranges from 1 to 0.01 m/s, assuming the gravel to be used have a permeability coefficient of 0.1 m/s and the size of gravel used is 24–16 mm.

4.2 Horizontal-flow roughing filter design

In this analysis, the pond is considered as a completely-mix reactor and in a steady-state. Evaporation is not considered due to the limited data. Calculation of mass balance analysis is conducted in two conditions, i.e. at the highest discharge and the lowest Biological Oxygen Demand (BOD₅) parameter value. It is intended to know the water quality condition at large discharge and the condition of water quality at its most critical. Dissolved Oxygen (DO) of water quality parameters are not considered because its value is good enough and close to the existing quality standard. The mass balance in the steady-state means the value of accumulated rate is zero ($dC/dt = 0$), and it is calculated by the following equation

$$C = \frac{Q_o C_o}{Q + K_T V} \quad (4)$$

with C_o replacing BOD_C, C replacing BOD_F, Q_o replacing Q_C , Q replacing Q_F . Thus the BOD_F is used for the calculation of BOD₅ in the pond as a whole.

The analysis of mass balance in the largest discharge use the data of the largest discharge in February 2012 was 2.54 m³/s, with BOD₅ water quality of 3 mg/L and TSS of 64 mg/L. The analysis of mass balance in the lowest discharge or it can be known as the most critical conditions use the data of the lowest water quality in February 2014 is water quality BOD₅ of 20.9 mg/L and TSS of 102 mg/L with a debit of 0.054 m³/s. Then the calculation of mass balance in the pond uses the equation 4.

The result is that the concentration of BOD₅ of pond during the largest discharge at Belik River is 7.99 mg/L and TSS pond is 170.65 mg/L. At the time of Belik River with the worst water quality condition, the BOD₅ value of pond is 55.73 mg/L and TSS pond 271.98 mg/L. Water quality values used as design variables of Horizontal-flow Roughing Filter is at the highest concentration of BOD₅ 55.73 mg/L and the highest TSS 271.98 mg/L.

To determine the depth of HRF, it used the maximum depth of pond of 1.5 m plus the freeboard of 20 cm in accordance with the design guidance, so that the total depth of HRF is 1.7 m. The first step to calculate the length of Horizontal-flow Roughing Filter is determining the value of BOD₅ and TSS of expected effluent that refers to Regulation of Governor of Yogyakarta Special Region Number 20 of 2008, of 14 August 2008 regarding Water Quality Standard in Yogyakarta Special Province [11]. According to its utility, the Belik river should be classified into the 2nd class water quality standard that has been designated for farming, crops irrigation, and/or other function that require the same water quality. Determining the output result that the water has been classified into second class, then the parameter BOD₅ is 3 mg/L and TSS is 50 mg/L.

The formula used in this calculation is the equation 8, the influent BOD₅ from result of mass balance analysis (S_i) is 55.73 mg/L, BOD₅ value of determined effluent (S_e) is 3 mg/L, oxygen absorption rate (K_T) is 0.15 1/day, the filter discharge (Q) is 133.8 m³/h.

Then the length of the filter (L) can be calculated from the water surface crossed area (S) by the calculation of filter height (1.7 m) multiplied with the length of filter (L), which is calculated by the equation 4:

$$\frac{S_e}{S_i} = \exp(-K_T S Q) \quad (4)$$

$$\frac{3}{55.73} = \exp(-(0.15 \times 24) \cdot (1.7 \times L) \cdot (133.8))$$

$$L = 2.20 \text{ m}$$

The TSS influent is known from mass analysis (S_i) is 271.98 mg/L, the determined value of TSS effluent (S_e) of 50 mg/L, oxygen absorption rate (K_T) is 0.15 1/day, the filter discharge (Q) is 133.8 m³/h. Then the filter width (L) can be calculated from the water surface crossed area (S) with the filter height calculation (1.5 m)

multiplied with the length of filter (L), which is calculated by the equation 4:

$$\frac{50}{271,98} = \exp(-(0,15 \times 24) \cdot (1,5 \times L) \cdot (133,8))$$

$$L = 2.50 \text{ m}$$

Based on the calculation results, the required filter length is 2.5 m. Thus, width and length of the proposed Horizontal-flow Roughing Filter have been determined. Therefore, the proposed Horizontal-flow Roughing Filter dimension data is as follows: length 44.6 m; total height 1.7 m and width 2.5 m.

4.2.1 Wire calculation analysis

There is wiremesh with SNI 03-0090-1999 standard legally sold in the market that is gabion shaped box with box dimension can be seen in Table 3.

Table 3. Dimension of Gabion wiremesh in the marketplace.

Type	L (m)	W (m)	H (m)	D (unit)
A	2	1	1	1
B	3	1	1	2
C	4	1	1	3
D	2	1	0.5	1
E	3	1	0.5	2
F	4	1	0.5	3

With the information of dimensions for the design of Horizontal-flow Roughing Filter, it can be calculated wiremesh required for gravel stone filter container. With long HRF dimension data (p) = 44.6 m; high (h) = 1.7 m; and width (l) = 2.5 m, it can be seen that the height of 1.7 m cannot be fulfilled according to the wiremesh box dimension in Table 3. However, based on market surveys, the height (H) of gabion can be ordered accordingly.

According to the data, then gabion box type C and F are selected and box modification according to the order (symbol P) with height (H) equal to 0.7 m, so that composition of gabion box in section can be seen in Figure 6.

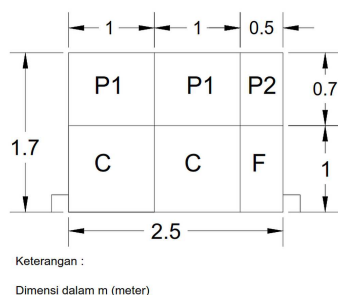


Fig. 6. Location of Horizontal-flow Roughing Filter design

Therefore, the need for wiremesh boxes in the construction design are as follows:

- Type C, size 4 m × 1 m × 1 m for 24 boxes
- Type F, size 4 m × 1 m × 0.5 m for 12 boxes
- Type P1, size 4 m × 0.7 m × 1 m for 24 boxes
- Type P2, size 4 m × 0.7 m × 0.5 m for 12 boxes

5 Conclusion

In conclusion, the UGM Retention Pond can be proven to be enabled not only as flood control pond but also can be utilized as an innovation of the watertreatment such as Horizontal-flow Roughing Filter. Based on the analysis that has been done, the design of HRF that can be applied as waterfilter has the spesification and dimension as can be seen in Table 4.

Table 4. Specification and dimension of proposed Horizontal-flow Roughing Filter

Name	Description
Location of Horizontal-flow Roughing Filter	Inside the pond near the input
Filter Media	Gravels, assuming that the coefficient of permeability, $k = 0.1 \text{ m/s}$
Size of filter media	24–16 mm
Filter efficiency target	94 %
Wiremesh	Type M7 with wire diameter of 7 mm and mesh spacing hole of 15 × 15 cm, gabion box, size: • 4 m × 1 m × 1 m for 24 boxes • 4 m × 1 m × 0.5 m for 12 boxes • 4 m × 0.7 m × 1 m for 24 boxes • 4 m × 0.7 m × 0.5 m for 12 boxes
Galvanis wire	Galvanis wire with spacing hole of 10 mm
Filter length	44.6 m
Filter width	2.5 m
Filter height	1.7 m
Filter volume	189.55 m ³

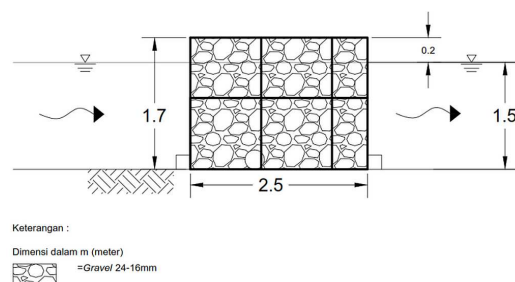


Fig. 7. HRF Cross Section.

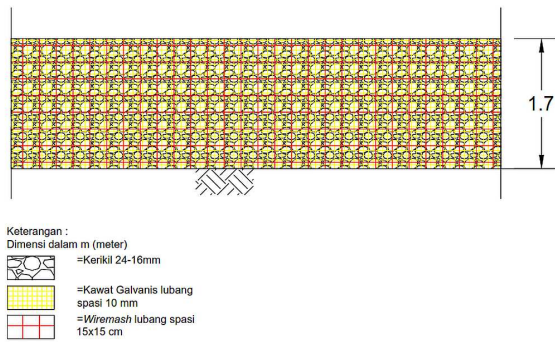


Fig. 8. HRF front look.

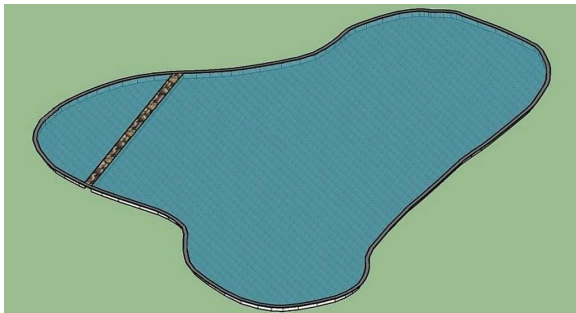


Fig. 9. 3D upper look of Horizontal-flow Roughing Filter.

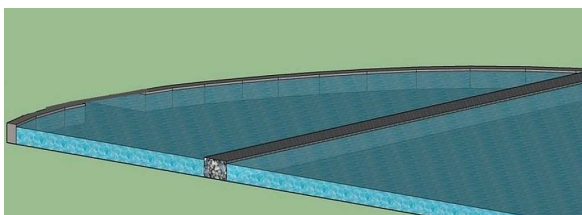


Fig. 10. 3D cross section of Horizontal-flow Roughing Filter.

References

1. Lee, S.-H., & J.M.J.C., J. KSCE J Civ Eng **2**, 187–193 (1998)
2. Losleben, T. R. *Thesis: Pilot Study of Horizontal Roughing Filtration in Northern Ghana as Pretreatment for Highly Turbid Dugout Water*. Massachusetts: Massachusetts Institute of Technology (2008)
3. Wegelin, M. Duebendorf: International Reference Centre for Waste Disposal (1986)
4. Wegelin, M. Duebendorf: Swiss Centre for Development Cooperation in Technology and Management (SKAT), CH-9000 St. Gallen, Switzerland (1996)
5. Nkwonta, O., Olufayo, O. A., Ochieng, G. M., Adeyemo, J. A., & Otieno, F. A. *Turbidity Removal: Gravel and Charcoal as Roughing Filtration Media*. South African Journal of Sciences, **106**(11/12) 5 pages (2010)
6. Nkwonta, O. Int J Phys Sci. **5**(8), 1240–1247 (2010)
7. Nkwonta, O., & Ochieng, G. *Roughing filter for water pre-treatment technology in developing countries: A review*. International Journal of Physical Sciences **4**(9), 455–463 (2009)
8. Metcalf & Eddy Inc. *Wastewater Engineering: Treatment Disposal and Reuse (Second Edition)*. Boston: McGraw-Hill, Inc (1979)
9. Mushila, C., Ochieng, G., Otieno, F., Shitote, S., & Sitters, C. J Global Res **2**, 136–144 (2016)
10. Badan Lingkungan Hidup Pemerintah Daerah Istimewa Yogyakarta. *Peraturan Daerah*. Retrieved Desember 1, 2017, from BLH Pemerintah Daerah Istimewa Yogyakarta (2013)
11. Gubernur Daerah Istimewa Yogyakarta. *Peraturan Gubernur Daerah Istimewa Yogyakarta Nomor 20 Tahun 2008 tanggal 14 Agustus 2008 tentang Baku Mutu Air di Provinsi Daerah Istimewa Yogyakarta*. Yogyakarta: Sekretaris Pemerintah Daerah Istimewa Yogyakarta (2008)