Civil Engineering Innovation for a Sustainable

Guest Editors:
Antoni
Ima Muljati
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PREFACE

Papers published in this edition of Procedia Engineering have been presented in The 5th Euro Asia Civil Engineering Forum (EACEF-5) at Petra Christian University, Surabaya, Indonesia, from 15-18 September 2015. The theme for EACEF-5 is ‘Civil Engineering Innovation for a Sustainable Future’. The conference was jointly organized by Petra Christian University, Surabaya, Universitas Pelita Harapan, Jakarta and Universitas Atma Jaya Yogyakarta, Yogyakarta, Indonesia.

Civil engineers and researchers in the field are challenged to play important roles and responsibilities in constructing a sustainable future. EACEF-5 conference provided a platform for sharing ideas and findings, as well as the challenges involved. Publication of all of the aforementioned papers in Procedia Engineering enables a wider circulation of the valuable thoughts contained in the papers.

The Editors would like to express their highest gratitude to all of the contributing authors of the papers published in this volume, as well as to the Organizing Committee and other parties involved.

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Water turbidity impact on discharge decrease of groundwater recharge in recharge reservoir

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Abstract

The need for groundwater supply is increasing. However, with excessive exploitation, the groundwater table has drawn down, and thus resulted in land subsidence, seawater intrusion and groundwater deterioration. In order to maintain the groundwater supply, various attempts, such as the use of natural or artificial recharges, have been done. One of the artificial recharging methods which were previously studied was recharge reservoir construction in the soils with permeability less than $10^{-5}$ cm$^3$/sec using a sand column. However, sedimentation could occur at a site where the recharge reservoir was constructed. Therefore, the levels of water turbidity, which could lead to sedimentation and blockage of groundwater flow (seepage), should be investigated. This research aimed to investigate the rate of blockage impact resulting from sedimentation in the sand column. More specifically, the aim of the research was to determine what types of sand column should be used in the field to minimize the groundwater problems. Experimental tests were carried out in the laboratory to measure the discharge of seepage through the soil layers and the sand column. The size of the physical model testing instrument was 180 cm x 115 cm x 60 cm with 12 pieces of the sand column (35 cm high), the reservoir water level of 10 cm, and three variations of water turbidity and deposition time. The research revealed that the higher the water turbidity, and the longer the period of deposition, the less the flow rate of groundwater recharge. As a result, turbid water should be prevented to infiltrate sand columns in recharge reservoirs.

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1. Introduction

Based on studies performed by The Ministry of Research and Technology since 2003, the use of recharge reservoirs has been able to minimize the impact of annual flood and drought in Indonesia due to their capacity to absorb great amount of water. Such capacity has been investigated with the simulation of a recharge reservoir in the University of Indonesia at an area of 0.5 ha using finite difference. This study indicated that the reservoir could absorb surface water with infiltration rate of 1,933 m³/day [1,2]. Another study was also carried out in Sleman, Yogyakarta using the Tambakboyo recharge reservoir with an inundated area of 5.6 ha and storage volume of 427,349 m³. This study showed that the reservoir could absorb water into the ground at an average rate of 2,969 m³/day, indicating contribution to water supply for 49,479 people in Yogyakarta [3]. Simulated modelling design of a recharge reservoir using tank model in Bogor city was also studied by [4]. This simulation showed that the recharge reservoir could absorb water 1,150 m³/day into an aquifer layer. A recent study performed by [5] using sand columns in low-permeability soils at the base of the recharge reservoir indicated water absorption with the amount of 5.39 m³/day for density of 0.0157.

However, the flow of turbid water into a recharge reservoir causes sedimentation which can lead to very slow water absorption even it is sustained to reach an aquifer layer. As a result, the recharge reservoir may not work properly. Currently, one of recharge reservoirs in Indonesia, such as Griya Martubung Reservoir in Medan, does not work properly due to sedimentation. This has caused inundation during intense rainfall due to its less-capacity of rainwater absorption into the ground. The objective of this research is to study the use of sand column model in a recharge reservoir. This study also investigates the impact of water turbidity on groundwater recharge in recharge reservoirs.

2. Literature review

Groundwater crisis, especially in large cities in Indonesia has reached a severe level. Groundwater recharge tends to decrease whereas the groundwater utilization significantly increases. The superblock and high-rise building constructions also exploit groundwater supply. The building structures with deep basement also reduce the ground capacity to absorb rainwater. Meanwhile, the availability of green open spaces for water storage during rainy season has decreased [6].

According to [7], surface water quality in Jakarta is very poor that prompts people to consume groundwater. However, uncontrolled exploitation of the groundwater results in lowering groundwater table from 50 m to 150 m in depth, leading to land subsidence and inundation of seawater along beach areas. In Bandung and surrounding areas, if no restoration was carried out for the groundwater condition in 2013, there would be additionally critical and damaged zones of 116 % and 570 % [8].

2.1. Groundwater

Groundwater is the most important mineral resource obtained from underground at the zone of saturated soils. In Indonesian regulation UU No.7, 2004, it is declared that groundwater exists in the rock layer [9]. About 30% daily water consumption in the world is obtained from groundwater, indicating its significant contribution to daily human life and efforts. The rest of water consumption is supplied by surface water from rivers and lakes [6].

Groundwater requires energy to flow through spaces between soil particles, indicated by groundwater table (piezometric level) in a local area. Groundwater flows from a point with high potential energy to another with low potential energy while no groundwater flow among points with the same potential energy. Imaginary line connecting points with the same potential energy is called as groundwater surface contour line or isohypse line. Along the contour line, there is no groundwater flow because the flow direction is perpendicular to the contour line.

2.2. River water turbidity

Surface water, especially in rivers, usually has a high level of turbidity during the rainy season as shown in Fig. 1. Environmental degradation, particularly related to widely decreasing forest areas followed by agricultural practices ignoring the conservation rules, has given significant contribution to the alteration of river flow characteristics and the increase of turbidity. Turbidity is the amount of granules inundated in the water. Substances causing turbidity
include: clay, mud sediment, organic and non-organic materials consisting of fine granules, soluble organic color mix, plankton and microorganism [10].

Turbidity is caused by organic and non-organic substances that are suspended and dissolved, such as mud and fine sand. Turbidity is stated in a turbidity unit which equals to 1 mg/liter SiO$_2$. The first equipment used to measure turbidity is Jackson Candler Turbidimeter, which was calibrated using silica. This Jackson Candler Turbidimeter is then used as standard equipment for turbidity measurement. One turbidity unit of Jackson Candler Turbidimeter is stated in 1 JTU unit. The Jackson Candler Turbidimeter is a visual measurement that compares water sample to the standard. Water turbidity is also often measured with Nephelometric method. In this method, light source is passed through the sample and the light intensity reflected by materials which cause the turbidity measured using the formazin polymer suspension as the standard solution. NTU (Nephelometric Turbidity Unit) is a unit to measure turbidity when using the Nephelometric method. Suspended density is positively correlated to turbidity. The higher the value of suspended density the higher the level of turbidity. Various levels of water turbidity are presented in Table 1.

Table 1. Water turbidity level.

| No | Turbidity level | TSM (NTU) |
|----|----------------|-----------|
| 1  | Fairly turbid   | 15 – 25   |
| 2  | Rather turbid   | 25 – 35   |
| 3  | Turbid          | 35 – 50   |
| 4  | Very turbid     | > 50      |

2.3. Recharge reservoir

One of artificial recharges is a recharge reservoir mainly used as the medium of water absorption that enables water to be easily and quickly absorbed into the aquifer layer. This reservoir model is suitable for areas with shallow groundwater table and the availability of wide areas [12, 13]. The recharge reservoir construction is different from the construction of common reservoirs. The recharge reservoir bed is directly connected to the aquifer layer. Principally, the recharge reservoir can be classified as a single purpose reservoir that is used to control flood for optimization of the aquifer usage with the increase of water storage capacity in the aquifer layer. The study performed by the Ministry of Research and Technology indicated that the absorption level (infiltration rate) of the recharge reservoirs was quite high.

2.4. Physical model of sand column

Sand column is used as a medium to absorb water in recharge reservoirs into the aquifer layer. The traditional method for constructing a sand column is drilling hole in a low-permeability clay layer and refilling it with coarse-
graded sand. Seepage through the sand columns should not bring fine soil particles (piping). Surface water is stored in the reservoir with a certain level, then it is flown through the sand columns with relatively high permeability to accelerate and enlarge recharge. The sand columns are also expected to filter the absorbed water, so only clean water can reach the aquifer layer [5,13].

3. Research method

Data collection was carried out using model testing as shown in Fig. 2. The rectangular container (180 cm x 115 cm x 60 cm) was used to perform this test [13]. This model used 12 sand columns (5 cm in diameter and 35 cm in height) with distance of 11.5 cm from one to adjacent columns. Selected soils, clays and sand columns which met the permeability requirement, were put into the container. Crushed stone was put on the container base as an aquifer layer. The rates of intake water flow $Q_1$ and $Q_2$ were varied within 3 levels of water turbidity i.e.: fairly turbid (21 NTU), rather turbid (30 NTU) and turbid (42 NTU). The intake water $Q_1$ flows through the sand columns to reach the aquifer layer whereas the intake water $Q_2$ directly flows through the aquifer layer. All the intake water $Q_1$ can either flow out through runoff $Q_3$ or flow out of the aquifer layer $Q_4$ while the intake water $Q_2$ can only flow out of the aquifer layer $Q_4$.

![Fig. 2. Model testing by using sand column.](image)

To measure the rates of flow into the container ($Q_1$ and $Q_2$), runoff ($Q_3$) and flow out of the aquifer layer ($Q_4$), filling time into the measuring cup per 1000 ml was recorded for 5 times. When the soil reached saturated condition, observations were performed for each of the 3 levels of water turbidity. Decrease of flow rate with deposition time was observed for 3 variations of sand column permeability as described in the following section.

4. Results and Discussions

The flow rates of groundwater recharge resulting from the observations for 3 variations of sand permeability were described in the following sections. The results showed that the flow rate of groundwater recharge decreased with the increase of water turbidity and deposition time.
4.1. Groundwater flow through high-permeability sand \((k = 0.201 \text{ cm/sec})\)

The flow rates of groundwater recharge through high-permeability sand (HPS) were presented in Table 2. The flow rate of groundwater with high level turbidity, such as turbid water, rapidly decreases with the increase of deposition time. In contrast, the flow rate of groundwater with low level turbidity, such as fairly turbid, slowly decreases with the increase of deposition time. Initially, the flow rates are the same \((56.51 \text{ cm}^3/\text{sec})\) among groundwater with the three levels of turbidity, then their flow rates continuously decreases as deposition time increases. However, the rate of these decreases is greater for groundwater with a higher level of turbidity. Such phenomenon can be attributed to the same permeability of sand columns in initial condition, then their permeability decreases in different rates imposed by groundwater with different levels of turbidity as deposition time increases. Turbid water makes much more granules deposited in pore spaces of the sand than less turbid water, such as rather turbid and fairly turbid respectively.

| Deposition time (hours) | Fairly turbid | Rather turbid | Turbid |
|--------------------------|---------------|---------------|--------|
|                          | Volume (cm³) | Vol. decrease (%) | Volume (cm³) | Vol. decrease (%) | Volume (cm³) | Vol. decrease (%) |
| 0                        | 56.51         | 0.00            | 56.51         | 0.00            | 56.51         | 0.00            |
| 1                        | 55.71         | 1.42            | 54.70         | 3.20            | 53.30         | 5.68            |
| 2                        | 55.31         | 2.12            | 53.20         | 5.86            | 51.10         | 9.57            |
| 3                        | 54.21         | 4.07            | 51.60         | 8.69            | 47.90         | 15.24           |
| 4                        | 53.61         | 5.13            | 50.20         | 11.17           | 44.00         | 22.14           |
| 5                        | 53.31         | 5.66            | 47.80         | 15.41           | 38.70         | 31.52           |
| 6                        | 52.01         | 7.96            | 43.70         | 22.67           | 33.90         | 40.01           |

4.2. Groundwater flow through medium-permeability sand \((k = 0.034 \text{ cm/sec})\)

The effects of water turbidity on decrease in flow rates of groundwater through medium-permeability sand (MPS) with deposition time were presented in Table 3. These effects were in line with the flow rates through the HPS but they were generally less significant than those through the HPS. Although percentages of decrease in the flow rates relative to the initial flow rate \((26.67 \text{ cm}^3/\text{sec})\) were only slightly less than those through the HPS, the amount of decrease in the flow rates was much less than those through HPS due to much lower initial flow rate through the MPS \((26.67 \text{ cm}^3/\text{sec})\) than the HPS \((56.51 \text{ cm}^3/\text{sec})\). This could be ascribed to smaller pore spaces where granules were deposited in the MPS than those in the HPS.

| Deposition time (hours) | Flow rates for different levels of water turbidity, \(Q_a\) (cm³/sec) |
|--------------------------|---------------------------------------------------------------|
|                          | Fairly turbid | Rather turbid | Turbid |
|                          | Volume (cm³) | Vol. decrease (%) | Volume (cm³) | Vol. decrease (%) | Volume (cm³) | Vol. decrease (%) |
| 0                        | 26.67     | 0.00            | 26.67     | 0.00            | 26.67     | 0.00            |
| 1                        | 26.30     | 1.39            | 25.80     | 3.26            | 25.20     | 5.51            |
| 2                        | 26.10     | 2.14            | 25.10     | 5.89            | 24.10     | 9.64            |
| 3                        | 25.60     | 4.01            | 24.40     | 8.51            | 23.10     | 13.39           |
| 4                        | 25.30     | 5.14            | 24.00     | 10.01           | 21.60     | 19.01           |
| 5                        | 25.20     | 5.51            | 23.40     | 12.26           | 20.10     | 24.63           |
| 6                        | 24.50     | 8.14            | 22.20     | 16.76           | 19.20     | 28.01           |
4.3. Groundwater flow through low-permeability sand \((k = 0.023 \text{ cm/sec})\)

The flow rates of groundwater recharge through low-permeability sand (LPS) were presented in Table 4. The results showed relatively negligible effects of water turbidity on decrease in flow rate of groundwater with deposition time due to its very low initial flow rate \((7.22 \text{ cm}^3/\text{sec})\) with respect to the initial rates through both the MPS and HPS. This can be attributed to very small pore spaces of the sand in initial condition, so only small decrease of the pore spaces can be imposed by the deposition of granules even from turbid groundwater. The flow rates of groundwater for the three levels of turbidity only showed very small decrease within 6 hours deposition time. Nevertheless, reduction rate of turbid groundwater flow was still slightly higher than those of rather and fairly turbid groundwater respectively.

| Deposition time (hours) | Flow rates for different levels of water turbidity, \(Q_a\) (cm\(^3\)/sec) | Volume | Vol. decrease (%) | Volume | Vol. decrease (%) | Volume | Vol. decrease (%) |
|-------------------------|----------------------------------------------------------------------|--------|------------------|--------|------------------|--------|------------------|
| 0                       |                                                                     | 7.22   | 0.00             | 7.22   | 0.00             | 7.22   | 0.00             |
| 1                       |                                                                     | 7.10   | 1.66             | 7.00   | 3.05             | 6.80   | 5.82             |
| 2                       |                                                                     | 7.10   | 1.66             | 6.80   | 5.82             | 6.50   | 9.97             |
| 3                       |                                                                     | 6.90   | 4.43             | 6.70   | 7.20             | 6.30   | 12.74            |
| 4                       |                                                                     | 6.80   | 5.82             | 6.60   | 8.59             | 6.00   | 16.90            |
| 5                       |                                                                     | 6.80   | 5.82             | 6.30   | 12.74            | 5.60   | 22.44            |
| 6                       |                                                                     | 6.60   | 8.59             | 5.90   | 18.28            | 5.30   | 26.59            |

The effects of water turbidity and sand permeability on the flow rates of groundwater with deposition time were clearly illustrated in Fig. 3. The results generally indicated more significant effect of water turbidity on decrease in flow rates of groundwater with deposition time through the HPS than those through the MPS and LPS respectively. These are in line with the initial flow rates of groundwater through the HPS \((56.510 \text{ cm}^3/\text{sec} \text{ for an area of } 2.07 \text{ m}^2 = 2.357 \text{ m}^3/\text{day/m}^2)\) which is significantly greater than those through the MPS \((0.624 \text{ m}^3/\text{day/m}^2)\) and LPS \((0.301 \text{ m}^3/\text{day/m}^2)\) respectively. Even the initial flow rate through the HPS is much greater than those resulting from previous studies carried out in Bogor City \((0.387 \text{ m}^3/\text{m}^2)[4]\) and in Sleman, Yogyakarta \((0.053 \text{ m}^3/\text{day/m}^2)[3]\). However, this flow rate decreases more significantly with deposition time than those through sand with medium and low-permeability respectively. In the long run, the flow rate of turbid water through the HPS may reduce into lower values than those through the MPS and LPS respectively but it seems unlikely for fairly turbid water. Therefore, high-permeability sand columns should be used in recharge reservoirs to provide great amount of groundwater recharge when there is a mechanism to prevent flow of turbid water either into a recharge reservoir or through sand columns.

The reduction rates of groundwater flow through the HPS also significantly diverge among different levels of water turbidity as deposition time increases. The divergences become smaller as sand permeability decreases. When groundwater flows through sand columns, granules in groundwater will be deposited in pore spaces between sand particles leading to the pore space reduction. This mechanism reduces the flow rate through the sand columns as deposition time increases. The large pore size of high-permeability sand enables great amount of granules to be deposited in the pore spaces whereas only small amount of the granules can be deposited in the pore spaces of low-permeability sand. As a result, the more turbid the groundwater the greater the amount of granules will be deposited in the pore spaces particularly for high-permeability sand. This leads to greater differences of reduction rate of groundwater flow with deposition time among the three different levels of water turbidity but it is not so for low-permeability sand due to its very small pore spaces in initial condition. Therefore, turbid water should be avoided to flow either into recharge reservoirs or through sand columns for maintaining their maximum capacity. This can be achieved by using filter at entry gate of water flow into reservoirs or at the top of sand columns. The use of lower-permeability sand can also become filter to minimize deposition of granules in the sand pore spaces.
Fig. 3. Comparison of the flow rate of groundwater recharge with three levels of turbidity (fairly turbid, rather turbid and turbid) through sand columns with three different values of permeability (HPS, MPS and LPS).

5. Conclusions

The following conclusions can be drawn from this study:

- Using sand columns in a recharge reservoir have produced high capacity of water absorption (0.301 - 2.357 m$^3$/day/m$^2$) into the aquifer layer as shown in this study. This capacity is generally higher than those obtained from previous studies carried out in Bogor city (0.387 m$^3$/day/m$^2$) and Sleman, Yogyakarta (0.053 m$^3$/day/m$^2$). However, this study used a small-scale model, thus construction of recharge reservoirs should be adjusted in a real field to obtain such high absorption capacity. Therefore, the use of sand columns in recharge reservoirs would be an alternative solution to cope with the impacts of inundation and draught which usually occur in Indonesia every year.

- Turbidity of surface water has shown significant impact on decrease in flow rate of the water into the ground with deposition time. The use of high-permeability sand columns in recharge reservoirs can absorb considerable amount of water into the ground, but turbid water will significantly decrease the groundwater flow rate with deposition time. Therefore, high-permeability sand columns should be used in recharge reservoirs when there is a mechanism to prevent turbid water entering the reservoirs. Using filter material such as a graded-sand or geotextile layer on the top of sand columns might be an alternative to prevent sedimentation in pore spaces between sand particles. However, lower-permeability sand columns could also be considered when turbid water is unavoidable to flow in recharge reservoirs because this type of sand could be a filter to minimize deposition of granules in the sand pore spaces. Clearance of sediments in recharge reservoirs is also required every dry season to maintain their allowable capacity to absorb surface water.

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