IJET EXPLORE International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 4 No. 10, October, 2014

Performance Analysis of Sand Columns in Recharge Reservoir

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ABSTRACT

The objective of this research was to analyze the performance of sand columns on groundwater recharge placed in the base of the dam as an effort to overcome the groundwater crisis. This research is a laboratory experiment which covers sand and soil permeability test, physical modeling of recharge reservoir with and without sand columns which will produce the water recharge rate flows into aquifer with several parameters e.g. surface water thickness in the dam, soil layer thickness/the height of sand column, number of sand column and head difference, each parameter consist of 3 variables. Based on the analysis, the maximum debit of water flowed through soil layer is 0,618 cm^3/sec, while through the sand column is 62.41 cm^3/sec with density 0.0157. Result of the research showed that the utilization of sand columns on recharge reservoir significantly influences the increase of amount of water flows into aquifer and head difference, soil layer thickness, surface water thickness and sand columns density also have significant effect. There was an increase of recharge rate due to the head difference increment 24,39%, surface water thickness 13,46% and sand columns density 742.81%. While in each increment of soil layer thickness, there was a decrease of recharge rate of water flows into aquifer around 5.43% (maximum). The performance of sand columns utilization compare to the condition where no sand columns used is around 0.9901 with the sand columns density 0.0157.

Keywords : *performance, recharge reservoir, sand columns*

1. INTRODUCTION

The rapid growth of the city which is marked with the presence of the settlement and industrial area has made the volume of freshwater need increases significantly and creates the imbalance of water supply and demand. This condition severed by the poor water service done by the government through the state water services which is not cover all areas as the result of limited production and undetected pipe leakages, thus the people's need on clean water is insufficiently fulfilled. Therefore people accessed groundwater as an alternative way by withdrawing it through well pumping. If the groundwater table is continuously decreased as the effect of groundwater excessive withdrawal, this situation will lead to saline intrusion, land subsidence and groundwater quality deterioration [1]. To cope with this problem, water recharges into aquifer artificially and naturally need to be accelerated. One way to perform artificial recharge is by constructing recharge dam which has more ability to infiltrate the surface water (run off) compared to pond which is so far commonly used as water reservoir, because recharge dam is designed to reach aquifer layer which has high absorbance capability (hydraulic conductivity) that is more than 10^{-5} m/s [2]. Unfortunately there is a problem when the recharge reservoir has to be built in the area which has low hydraulic conductivity. This situation will slow down the water to reach the aquifer layer and then the recharge reservoir will not work effectively. Therefore in this research we examined the utilization of recharge column model which employs sand as the filler material and placed it on the base of recharge reservoir and directly connected to the semi confined aquifer layer with several parameters. Hopefully this can be a solution to the problem off groundwater recharge. The objective of this research is to explore the influence of head difference, soil layer thickness/height of sand column, surface water thickness and sand column density subject to the recharge rate of water flows into aquifer and also to analyse the performance of sand column utilization.

II. GROUNDWATER CRISIS ISSUE

Water is crucial for commercial activities such as for industry, agriculture, fisheries and other urban businesses. People access water from many sources both from the ground surface (surface water) and the deep ground (groundwater). Although the amount of total water in earth is around 1.360.000.000 km^3 or covers almost 75% of earth surface, but 97.1% of that is in the form of seawater which contains high levels of salt and cannot be consumed, while in the form of snow and glaciers is around 2.283% and the amount of water that potentially to be used by human naturally or processed first is only
0.617%, consists of water from the rivers and lakes

0.017% and groundwater 0.6% [3].Thus it is clear that the portion of freshwater (groundwater) on earth is very small while when the human population is increased, so does the freshwater need.

But the current excessive groundwater exploitation has induced some negative impacts like saline intrusion which can severe the groundwater crisis.

III. RECHARGE RESERVOIR

1. The Function of Recharge Reservoir

Recharge reservoir is a typical reservoir that has primary function as water infiltration media which makes the surface water flows into aquifer easily and quickly. This typical reservoir is suitable for the wide area with the shallow groundwater table [4]. While the chairman of recharge reservoir development project from The Ministry of Research and Technology Indonesia, said : "The basic philosophy in recharge reservoir development is how to minimize the surface run off and to increase the capability of the soil to infiltrate surface water flow" [5].

The functions of recharge reservoir are:

1. Optimize the function of aquifer by enhancing its storage capacity.
2. Can be used as the flood control tool in the downstream area.
3. As the freshwater backup in dry season [6], [7].

2. Sand Column

Sand column is media which is expected can absorb the water form reservoir and take it into aquifer. The traditional way to create the sand column is by making bore holes on the clay soil layer which has low permeability and refill the holes with the gradated sand. Sand must let the water flow without having the fine soil particles removed. [8].

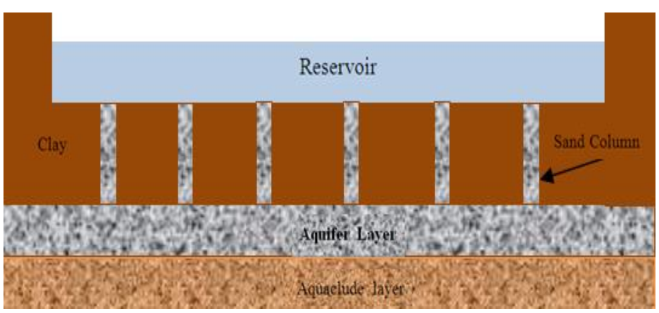

Fig. 1 The concept of recharge reservoir with sand columns

The figure 1, shows the sketch of sand columns utilization with a principle that water from the surface is collected in the reservoir (dam) with a specific thickness of surface water. The water then is introduced through the sand columns with the expectation that sand with its high permeability can accelerate and increase the recharge rate and at once can be a filter for water that flows into aquifer.

3. Sand Column Density

Sand columns density is the ration between the surface area of the sand column (A') with the surface area of recharge reservoir (A), or can be written in the form of equation:

$$A' = \frac{1}{4}\pi D^2 n \quad (1)$$

$$\mathfrak{z} = \frac{A'}{A} \quad (2)$$

Where $\mathfrak{z}$ is sand column density, *D* is sand column diameter, *n* is total number of sand columns.

IV. RESEARCH METHOD

This research consists of several phases as follow:

First phase: Preparation of materials and instruments

In this phase, soil and sand sampling and instruments preparation were conducted.

Second phase: Physical modelling test

Recharge reservoir physical model test was conducted to determine the magnitude of groundwater recharge rate occurs through the layers of soil and sand columns. At this stage consists of two models they are physical model of the recharge reservoir without sand columns and recharge reservoir physical model with sand columns.

1. Recharge reservoir physical model testing without sand columns.

This study used a rectangular 3D physical model test with outer dimension 180 cm x 115 cm x 60 cm and some holes at the bottom of the model worked as seepage outflow holes. The soil material that has been tested through soil property and permeability test and qualified for research material, put in the rectangular tank model with dimension 150 cm x 100 cm x 50 cm. Furthermore, an input flow (Q1) was imposed continuously at the surface of the tank so that surface water thickness can be constant while side flow (Q2) was given to define the magnitude of head difference. Similarly, run off discharge (Q3) and out flow discharge from aquifer layer (Q4) were imposed also to the model. To define the magnitude of the four flow rates, glass container (1000 ml) is filled out in time and this measurement was conducted 5 times for each flow debit.

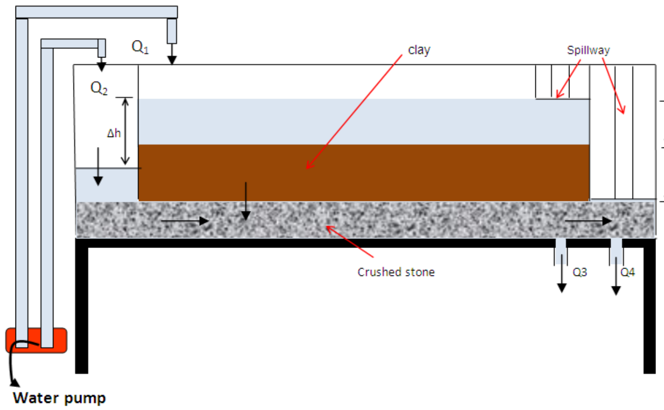

Fig. 2 : Physical recharge reservoir model testing without sand columns

When the flow condition has reached the steady state and the soil is fully saturated, characterized by the same inflow and outflow debit, the outflow debit from aquifer and head difference were measured and recorded.

Research activities in this physical model testing has 3 variations for each surface water thickness in reservoir (Hw), side flow debit (Q_2) and soil layer thickness (Ht).

$$Q_{at} = Q_4 - Q_2 \quad (7)$$

Where Q_{at} is the amount of water that flows into aquifer through soil layers, Q_2 is side flow debit, Q_4 is out flow debit from aquifer.

2. Physical recharge reservoir model testing with sand columns.

The same physical tank model that used in the model testing without sand columns was used in this stage. The only difference is the utilization of sand columns in soil layers. When soil condition was fully saturated, characterized by the same inflow and out flow debit, the outflow from aquifer and head difference were measured and recorded by filling out the glass container (1000 ml) in time and this measurement was conducted 5 times. Research activities in this physical model testing has 3 variations for each surface water thickness in reservoir (Hw), diameter of sand column (D), height of sand column (z), total number of sand column (n) and side flow debit (Q_2).

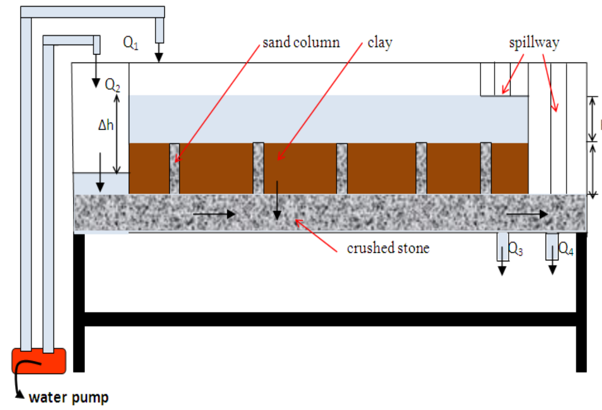

Fig. 3 Physical recharge reservoir model testing with sand columns

$$Q_{kp} = Q_4 - Q_2 - Q_{at} \quad (8)$$

Where Q_{kp} is the amount of water that flows into aquifer through sand columns, Q_2 is side flow debit, Q_4 is out flow from aquifer, Q_{at} is the flow through soul aquifer layers

Third Phase: Calculate the performance of sand columns by this equation:

$$\eta = \frac{Q\ kp - Q\ at}{Q\ kp} \quad (9)$$

Where η is the performance of sand columns, Q_{kp} is groundwater recharge rate through sand columns, Q_{at} is groundwater recharge rate through soil layers.

1. RESULT AND DISCUSSION

2. 1. Type of Soil

Based on the soil test, from the four of soil classification system, it is concluded that the soil used in this study is silty clay with low plasticity while the sand is coarse sand type.

2.The Inluence of Head Difference

Figure 4 showed the functional relationship between the debits entered the aquifer and the head difference in each soil layer thickness/height of sand columns.

The relationship is linear for both models with and without sand columns with various sand columns density. It can be seen that there is an increase of debit enters the aquifer along with the increment of head difference. This is caused by the decrease of water pressure which inhibits the water entering the aquifer from recharge reservoir. The maximum percentage of the increment of water debit enters the aquifer as the result of head difference's increment is 24.39%.

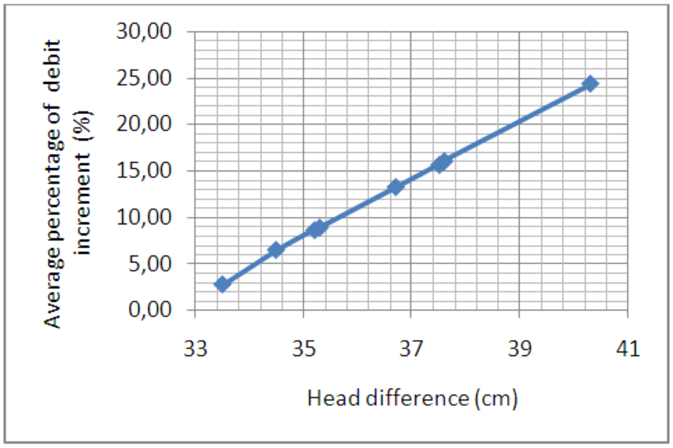

Fig. 4 Relationship of the averag percentage of debit increment with head difference

3.The Inluence of Soil Layer Thickness/Height of Sand Column

Based on figure 5, it can be seen that any increase of soil layer thickness/height of sand column, diminishing the inflow debit enters the aquifer, although the percentage is very small (<5%). This due to the bigger the soil layer thickness/height of sand column, the farther the water travels into aquifer.

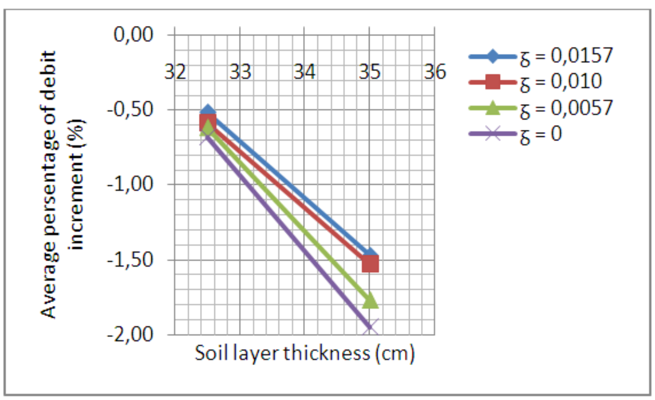

Fig. 5 Relationship of the average percentage of debit increment with the soil layer thickness (z)

The results are consistent with equation 8 that stated the relationship between the inflow debit enters the aquifer is inversely proportional to the soil layer thickness/height of sand column. The percentage of inflow debit reduction (minimum) is -0.52% with the sand columns density (ξ) = 0.0157. While the maximum percentage is -1.95% with the sand columns density (ξ) = 0.

4.The Inluence of Surface Water Thickness In Reservoir

It can be seen that the inflow debit enters the aquifer is increased along the increase of surface water thickness. This is due to the higher the surface water thickness in reservoir, the bigger the water pressure in the base of reservoir. This is also consistent with equation 6 that stated that the relationship between the inflow debit enters the aquifer is proportional to the surface water thickness. The percentage of the increment of inflow debit enters the aquifer (minimum) is 6.37% with the sand columns density (ξ) = 0. While the maximum percentage is 13.46% with the sand columns density (ξ) = 0.0079.

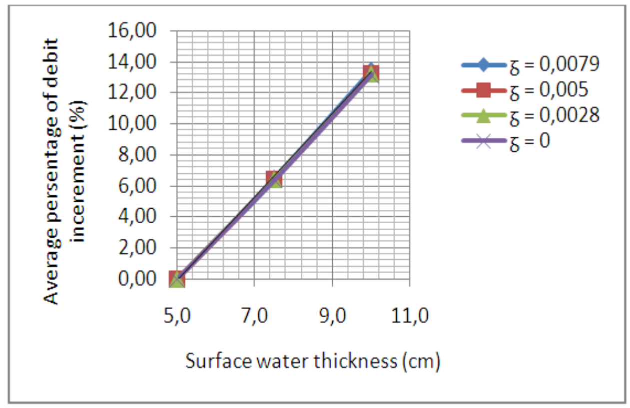

Fig. 6 Relationship of the average percentage of debit increment with the surface water thickness

5.The Inluence of Sand Column Density

It can be seen from figure 7 that the inflow debit enters the aquifer increase concurrently with the increase of the sand columns density.

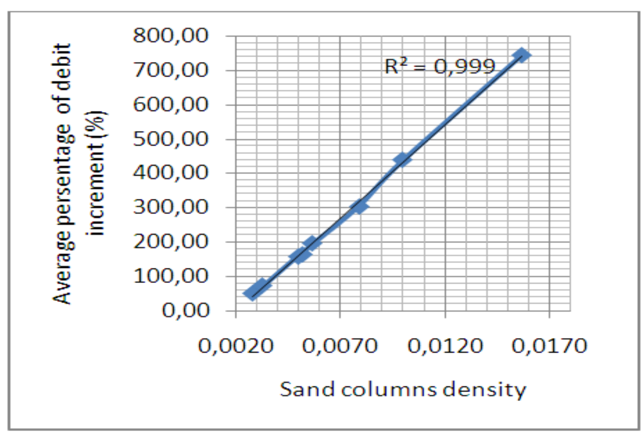

Fig. 7 Relationship of the average percentage of debit increment with the sand columns density

This is due to the bigger the sand columns density, the wider the surface area of sand columns and the bigger the amount of water flows into aquifer. The average percentage of debit increment of flows into aquifer minimum is 48.92% and maximum 742.81%.

6. The Performance of Sand Columns

From figure 8, it can be seen that the performance of sand columns in each sand columns density is considerably good. This is due to the property of sand which has high permeability coefficient that allows water to flow into the aquifer. With the sand columns density 0.0019 the average performance is 0.9163. Similarly with the sand columns density 0.0028 the average performance is around 0.9438. With the density 0.0033, the average performance obtained is 0.9513 while on the density 0.0050 the average performance is 0.9678. On the density 0.0052 the average performance is 0.9684. While on the density 0.0057 the average performance is 0.9724, on the density 0.0079 the average density is 0.9792. While on the density of 0.010, the average performance is 0.9844 and on the density 0.015, the average performance is 0.9901. From the results it is shown that, the greater the the sand columns density, the better the average performance. This strengthens the hypothesis that the inflow debit enters the aquifer is proportional to the surface area of the sand column as shown in Equation 6.

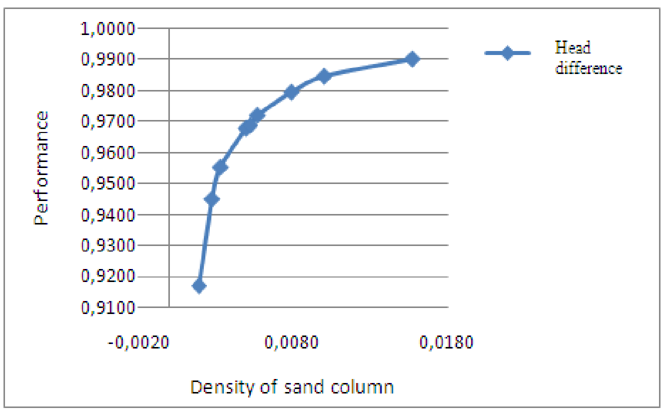

Fig. 8: Sand columns performance

3. CONCLUSION

Based on the result of the research, it can be concluded that:

1. The utilization of sand columns in recharge reservoir significantly influences the increase inflow debit which enters the aquifer layer with specific head difference, soil layer thickness/height of sand columns, surface water thickness and sand columns density. The maximum debit obtained through soil layers was 0.618 cm^3/sec while the debit obtained through sand columns was 62.41 cm^3/sec with the sand columns density 0.0157.
2. There is an increase of inflow debit enters the aquifer due to the addition several parameter namely: head difference is 24.39%, surface water thickness is 13.46% and sand columns density is 742.81%.
3. The percentage of inflow debit reduction due to the increase of soil layer thickness / height of sand columns is -1.95%.
4. The performance of sand columns utilization is very good compared to the condition without sand columns and it is around 0.9901.

Acknowledgement

We sincerely thank especially to Head of Civil Engineering Department, Polytechnic State of Ujung Pandang for supporting and providing opportunity to conduct this research.

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