The Effectiveness of Sand Column Utilization in Recharge Reservoir as Seawater Intrusion Barrier

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ABSTRACT - Excessive groundwater exploitation may cause groundwater decline and induce the landward movement of seawater in coastal aquifer and generate sea water intrusion. One of the efforts to overcome sea water intrusion is groundwater recharge using recharge reservoir. In this research, a recharge reservoir is built on an area with permeability coefficient less than 10-5 cm/sec, analyzed using sand column model and put on the recharge reservoir base which is directly connected to the aquifer layer. The objective of this research is to explore the utilization of sand column subject to the amount of groundwater recharge obtained. This research is an experimental laboratory study that includes the main recharge reservoir model with and without sand column. The data resulted from the research consists of recharge rate entering the aquifer within various parameters: head level differences, sand column or soil layer thickness, and sand column density. Each parameter consists of three variables. Results of the research showed that the maximum debit obtained was 62.41 cm3/sec with 0.00157 of sand column density, 37.4 cm of head difference and sand column height is 30 cm. It is expected that results of this study are applicable and can be implemented in the field scale to cope with the problem of sea water intrusion.

Keywords - Recharge reservoir, sand column, sea water intrusion.

I. INTRODUCTION

Excessive groundwater exploitation for fulfilling the demand of domestic, agriculture, industry and other commercial activity have caused groundwater decline, which will initiate seawater intrusion [3], [7], [8], [15]. To cope with this problem, various efforts have been taken by recharging water into the ground, either by natural or artificial methods to accelerate water absorbance [4], [5], [6],[12]. One of the methods is by employing recharge reservoir [15], [16]. Designed to reach the aquifer layer, this type of reservoir has the capability to absorb surface runoff significantly more than ponds or lake, which are currently more used as water reservoir [6], [13].

However, there will be a problem when the reservoir is built on a particular area with low permeability and absorbance ability where water will be very slow in reaching the aquifer layer and this may fail its function as a recharge reservoir [1], [2]. Therefore, it is required to study the utilization of sand column which put on the base of the recharge reservoir and directly connected to the aquifer layer within various parameters. This method is expected will provide solution to the problem of seawater intrusion. The objective of this study is to identify the groundwater recharge due to the use of sand column.

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II. SEAWATER INTRUSION

Seawater intrusion is a phenomenon where seawater enters the coastal aquifer [16]. This can be caused by various factors. Some of them are the change of the land use, mangrove deforestation, population and industrial growth in the area near to the coastline which uses groundwater as freshwater supply [11]. Such exploitation, especially excessive exploitation, may cause hydraulic disequilibrium of the freshwater-saltwater interface and cause the landward migration of seawater. In addition, the characteristics of the beach and the composing rocks, as well as the groundwater fluctuation in the beach area have contributed to seawater intrusion and have caused groundwater quality degradation. This can be seen from the increasing salinity of groundwater based on the chloride ion content indicated by the total dissolved density number and the groundwater conductivity. Seawater intrusion causes groundwater to change from freshwater to brackish water or even to saline water. When the groundwater fluctuation is high, the seawater intrusion probabilities are higher in reducing the groundwater quality [15].

In areas near to beach or ocean, freshwater and seawater zone are in contact and the line formed is called as the interface. It can be projected either to the sea or to the land depending on the amount of recharge from rainfall. When rainfall recharge is significantly high, the interface is moving seaward and conversely when the rainfall recharge is low or even none, the *interface* will be moving landward [15].

III. SOIL PERMEABILITY COEFFICIENT

Soil permeability coefficient is the amount of water flow in each time unit passing through one unit area of aquifer section [2]. To determine the soil coefficient permeability precisely, it is required to use laboratory method such as constant head test, which is used for soil with coarse granule and high permeability coefficient and also falling head test which is used for soil with fine granule and low conductivity.

Darcy law describes the capability of water to flow through the soil pores and the influencing characteristics. Flow velocity and the quantity/ /debit of water per unit time is proportional to the hydraulic gradient [3].

$$Q = k.i.A \tag{1}$$

$$V = \frac{Q}{A} = k.i \tag{2}$$

Where: Q = debit (cm3)
A = soil section area (cm2)
k = coefficient permeability (cm/sec)
i = hydraulic gradient
v = flow velocity (cm/sec)

IV. RECHARGE RESERVOIR

A. The Function of Recharge Reservoir

Recharge reservoir is one type of reservoir which is working mainly as the media to make the water easier to be absorbed to the aquifer layer. This type of reservoir is suitable for area with shallow groundwater surface and available in wide area [4]. According team leader of the recharge reservoir development project in Ministry of Research and Technology Indonesia, the basic development philosophy of recharge reservoir is how to minimize runoff and to increase the capability of the ground to absorb surface water. Recharge reservoir can be classified as *single purpose* reservoir, which is used for controlling flood with a working system that increases the optimization of aquifer function and raises the storing capacity of the aquifer layer [13] .

The utility of recharge reservoir includes:

1. To optimize the aquifer function and to increase th water storage capacity in the aquifer
2. To be worked as a flood control in upstream or runoff area.
3. To be used as water storage in dry season.

B. *Sand Column*

Sand column is a media which is expected to absorb the water in reservoir into the aquifer layer. The traditional method is by making drilled hole in the clay layer with small permeability and refilling it with the gradated sand. Sand should be flown with water efficiently without taking the fine particles. Figure 1 shows the sketch of sand column with a principle that water coming from the surface is stored in the reservoir within certain height. Then, water is flown through the sand column in order to have sand with higher permeability, to accelerate and enlarge the recharge and filtration that water entering the aquifer layer is in clean condition.

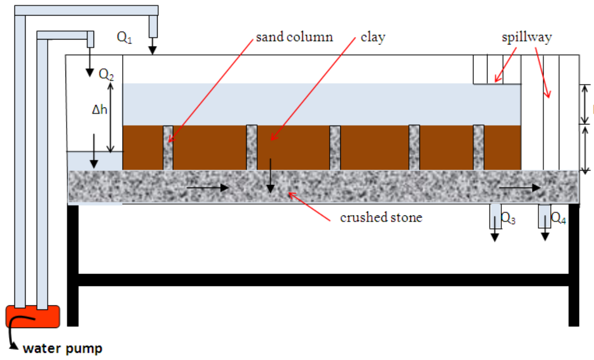

Fig. 1. The concept of recharge reservoir with sand column

C. *Sand Column Density*

Sand column density is a comparison between the surface area of sand column (A') and the surface area of recharge reservoir (A), or written in the flowing formula:

$$A' = \frac{1}{4}\pi d^2 N_{sc} \qquad (3)$$

$$A = p \times l \qquad (4)$$

$$= \frac{A'}{A} \qquad (5)$$

Where : = sand column density

d = sand column diameter

N_{sc} = number of sand column

p = reservoir length

l = reservoir width

V. EXPERIMENTAL SETUP

A. *Time and Location*

This study was carried out in the period of six months, starting from sample collection to the end of the test in The Soil Mechanic Laboratory and Hydraulic Laboratory of Civil Engineering Department of Politeknik State of Ujung Pandang. Sand samples were taken from district of Jeneberang river, Gowa district, and soil samples were taken from Tamalanrea Makassar city.

B. *Research Procedures*

This study consists of several steps:

1. Data collection

   Soil and sand samples were collected and instruments in the laboratory were prepared.

2. Laboratory test.

Laboratory testing consists of water content testing, sieve analysis and permeability analysis. The recharge reservoir model testing was carried out without sand column and with sand column within various parameters: reservoir height, soil later thickness / sand column thickness and the number of sand columns. Each parameter consisted of 3 variables.

Fig.2. Recharge measurement of water that entering the reservoir

Fig.3. Measurement of water recharge out from aquifer

3. Data analysis

Data resulted from observation to the recharge reservoir model testing with and without sand column was processed and plotted in a relationship graphic between recharge debit (Qa) with the available parameters. Based on the testing result of the physical model using the sand column, it was resulted in equation of recharge debit as the function of reservoir water height, sand column diameter, sand column height, and the difference head. In order to obtain qualified results, it was necessary to test the relationship strength between parameters and the validation to the research results.

VI. RESULTS AND DISCUSSIONS

A. Soil Type

The testing result of soil and sand sample based on the four soil classification systems indicated that the soil used in this research was silt with low plasticity and the sand was coarse.

B. Sand Column Height (z) of 30 cm

Figure 4 shows the increasing debit at energy level difference of 30.2 cm to 37.4 cm. Based on this figure, the difference of recharge debit is significant from density 0 to 0.0157. At density = 0, the minimum groundwater recharge debit was 0.50 cm^3/sec and maximum was 0.618 cm^3/sec. At density = 0.0057, the minimum groundwater recharge was 15.49 cm^3/sec and maximum was 19.19 cm^3/sec. At density = 0.010, the minimum groundwater recharge debit was 32.06 cm^3/sec and maximum was 39.72 cm^3/sec. At density = 0.0157, the minimum groundwater recharge debit was 50.4 cm^3/sec and maximum was 62.41 cm^3/sec.

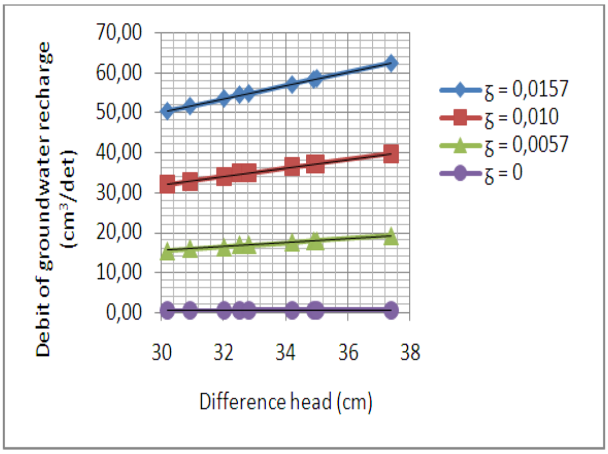

Fig. 4. The relationship of debit entering the aquifer and difference head at z =30 cm

C. Sand Column Height of 32.5 cm

Figure 5 shows the increasing debit at energy level difference of 32.4 cm to 40.3 cm. Similar to Figure 4, Figure 5 shows significant groundwater recharge difference at density 0 to 0.0157. At density = 0, minimum groundwater recharge debit was 0.497 cm^3/sec and maximum was 0.615 cm^3/sec. At density = 0.0057, the minimum groundwater recharge debit was 15.36 cm^3/sec and maximum was 19.11 cm^3/sec. At density = 0.010, the minimum groundwater recharge debit was 31.86 cm^3/sec and maximum was 39 cm^3/sec. At density = 0.0157, the minimum groundwater recharge debit was 50 cm^3/sec and maximum was 62.22 cm^3/sec.

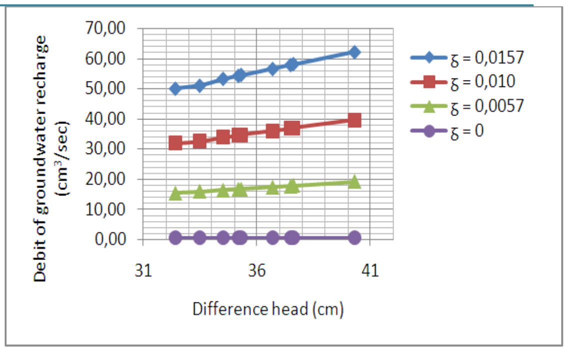

Fig. 5. The relationship of water debit entering the aquifer and head difference at z =32.5cm

D. Sand Column Height of 35 cm

Figure 6 shows increasing debit of energy level difference from 34.6 cm to 42.6 cm. Such as in Figure 4 and Figure 5, Figure 6 indicates significant difference of groundwater recharge debit from density 0 to 0.0157. At density = 0, the minimum groundwater recharge debit was 0.489 cm^3/sec and maximum was 0.608 cm^3/sec. At density = 0.0033, minimum recharge debit was 10.09 cm^3/sec and maximum was 12.46 cm^3/sec. At density=0.0057, the minimum recharge debit was 17.44 cm^3/sec and maximum was 21.46 cm^3/sec. At density = 0.0157, minimum recharge debit was 49.73 cm^3/sec and maximum was 61.21 cm^3/sec.

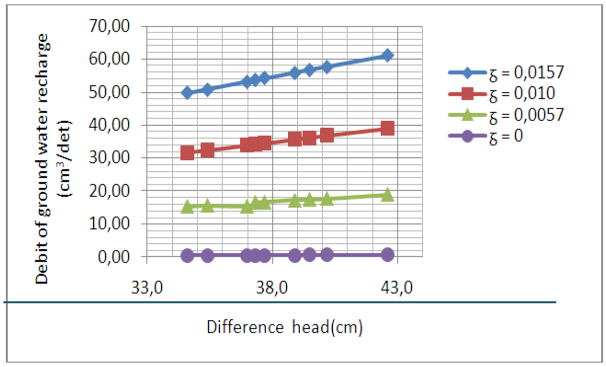

Fig. 6. The relationship of debit entering aquifer and difference head at z =35 cm

Figure 4, figure 5 and figure 6, describe the functional relationship between groundwater recharge debit and the head difference at every soil layer thickness or sand column height. The functional relationship was a linear relationship, both for recharge reservoir without sand column (density 0) and with sand column (various densities). The tendency of increasing groundwater recharge debit followed the same pattern with the increasing of energy level difference.

Based on the abovementioned explanation, it can be generally described that the average percentage difference of groundwater recharge difference due to the energy level difference at the soil layer thickness or the sand column height were 30 cm, 32.5 cm and 35 cm at all sand column density. This was due to the increasing difference head that would influence the level of increasing groundwater recharge debit. Then, it can be described that higher energy level difference would decrease the piezometric pressure that hampered the water entry from the reservoir water, both through soil layer and sand column to the aquifer layer. Results of this study are supported by Bernoulli equation and Darcy law which show direct proportional relation between debit and head difference.

VII. CONCLUSIONS

Based on the results of this study, several conclusions can be drawn as the followings:

1. The higher head difference and sand column density, the larger of the groundwater recharge debit will be. On the contrary the thicker the soil layer or the height of the sand column, the smaller the recharge debit obtained.
2. The maximum debit of 62.41 cm^3/sec occurred at 0.0157 density and 37.4 cm difference head with sand column height of 30 cm.
3. The sand column can be used in the recharge reservoir base with small permeability to buffer seawater intrusion.

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