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3
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6

Experimental and numerical modeling of sand column applied on recharge reservoir to control seawater intrusion

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Abstract. Excessive groundwater exploitation may lead to groundwater depletion, causing groundwater level at the inland lower than sea level and result in seawater intrusion (SWI) in a coastal aquifer. To control the occurrence of SWI, an alternative solution is to increase the replenishment of groundwater using a recharge reservoir. If a recharge reservoir is built in a region with soil hydraulic conductivity below 10⁻⁵ cm/s (semi impermeable), then a sand column is usually proposed, put on the bottom of the recharge basin and directly connected to the aquifer layer. The purpose of this study is to analyze the effectiveness of the sand column's application in the recharge reservoir to control SWI. This research is an experimental study that combines physical and numerical modeling of the recharge basin with sand columns under a laboratory scale. The results of this research are beneficial for field applications because the process that occurs in the recharge reservoir can be determined prior to the real construction in the field. The results of the research are also useful to investigate whether the recharge reservoir is effective or not as a buffer of SWI in coastal aquifers. The expected result is that by using sand columns in the recharge basin, seawater intrusion can be controlled. It is hypothesized that the higher the number of sand column density and water level on the reservoir, the farther the freshwater saltwater interface is pushed toward the sea.

1. Introduction

In some big cities, groundwater extraction is so intensive. Many industries, residential housings, and hotels utilize production well of up to 20 wells with a capacity of more than 8,000 m³ per day, resulting in a decrease of groundwater level that will impact in replacement of freshwater by seawater in coastal aquifers. This process is called as seawater intrusion (SWI). The intensity of groundwater extraction is deeply related to the amount of freshwater replaced by saline water inside aquifer [1]. If SWI has reached the production wells, then the freshwater in the wells will be contaminated and can no longer be used for daily usage. To overcome the problem, natural and artificial recharge by building absorption wells, bio pore holes or other absorption techniques have been done but the results sometimes are not optimal to maintain the minimal groundwater level required to control SWI. The recharge reservoir method that is currently developed in Indonesia can be a solution. However, the problem is that if the recharge reservoir is built in a region where its soil permeability is less than 10⁻⁵ cm/s (semi impermeable), then a sand column that placed on the bottom of the recharge basin and directly connected to the aquifer layer is required. For this reason, there will be an analysis to investigate the effectiveness of sand columns in the recharge basin as a buffer of SWI. Here, an



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experimental study is conducted by combining physical and numerical modeling under the scale of the laboratory.

2. Literature review

2.1. Seawater intrusion

It is understandable that the role of groundwater as a natural resource besides surface water for clean water supply is increasing since groundwater has several advantages over surface water [1]. For example, more hygiene because it has undergone a natural filtration process, its quality is relatively fixed, its investment is relatively low, and groundwater can be found easily. Communities, both individuals and groups need water for everyday purposes and for other needs. Water for drinking is a top priority compared to other needs. This means that the function of water as drinking water should be supported in order to meet the quality and quantity required [2]. Therefore, groundwater use should consider the balance and sustainability principles by filling more water into the soil, either by natural or artificial means.

The coastal zone as shown in figure 1, is territories that form low lying topography and morphology seen in the form of the coastal plain. Geologically, the constituent rocks are generally alluvial deposits consisting of clays, sand, and gravel resulting from the transport and erosion of rocks in the upper reaches of the river. Generally, the rocks in the plains are loose, so the potential of groundwater is quite good. The main problem in the coastal zone is the diversity of the aquifer system, positioning, and dispersal of seawater intrusion which is mostly caused by excessive groundwater extraction for the needs of fishermen and industry.

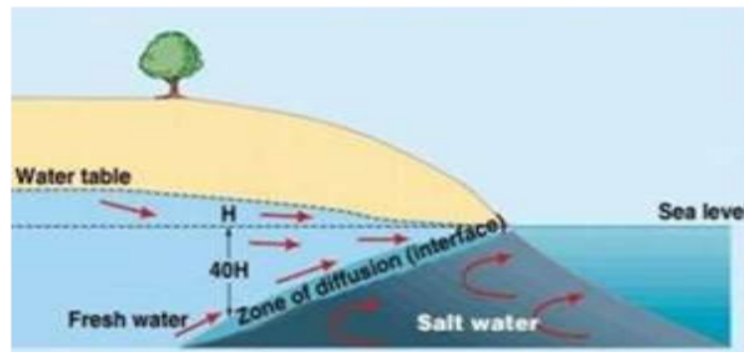


Figure 1. The cross-section of freshwater and seawater interface in coastal aquifers.

2.2. Positioning

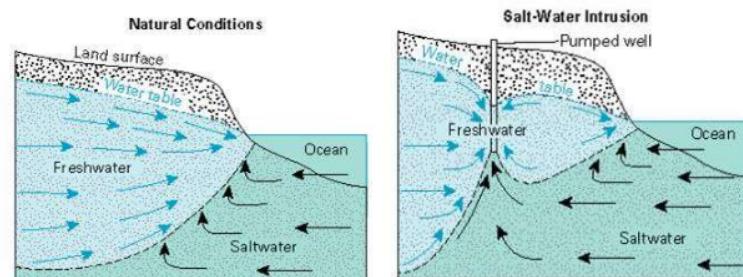


Figure 2. Interface conditions that are natural and already experienced SWI.

Naturally, seawater cannot enter far into the mainland because freshwater in the aquifer has a piezometric that is higher than seawater so that the interface is formed as the boundary between freshwater and seawater. It is the state of equilibrium between seawater and freshwater in the aquifer.

Seawater goes into the aquifer system passes through two systems, namely SWI and up coning as shown in figure 2. Under natural conditions, groundwater from the land will flow continuously into the sea and this called freshwater discharge. Saltwater density is slightly larger than freshwater density, thus seawater will push freshwater in the aquifer more inland. Because water pressure in the aquifer is higher than sea level, the pressure can be neutralized and the freshwater discharges to the sea, creating a balance between seawater and freshwater [3]. Seawater intrusion occurs when this balance is disrupted. Activities that cause seawater intrusion include groundwater extraction through excessive pumping, coastal characteristics and constituent rocks, groundwater head, and groundwater fluctuations in coastal areas [4,5]. According to Ghyben - Herzberg concept, saltwater is found at a depth of 40 times the freshwater head above sea level. This phenomenon is caused due to differences in gravity between seawater (1025 g/cm^3) and freshwater type (1000 g/cm^3). So, we get the value of $z = 40 \text{ hf}$. where: hf = groundwater head above sea level (m); z = interface depth under sea level (m); ρ_s = density of seawater (g/cm^3); ρ_f = density freshwater (g/cm^3). There are several ways to control SWI, such as;

2.2.1. Changing the pumping pattern

Moving the pumping location from the coast to the upstream will increase the slope of the hydraulic slope towards the sea, resulting in water pressure in the aquifer will grow as shown in figure 3. The freshwater level in the aquifer is raised by artificial recharge. For unconfined aquifers, it can be done by spreading water on the surface of the soil, whereas in the confines aquifer, it can be charged directly into the aquifer. In this research, the recharging water will be filling into the aquifer by placing the sand column in the recharge basin. The method has never been done either in the form of research in laboratory or application in the field a table is divided into parts these should be labeled (a), (b), (c), etc but there should only be one caption for the whole table, not separate ones for each part.

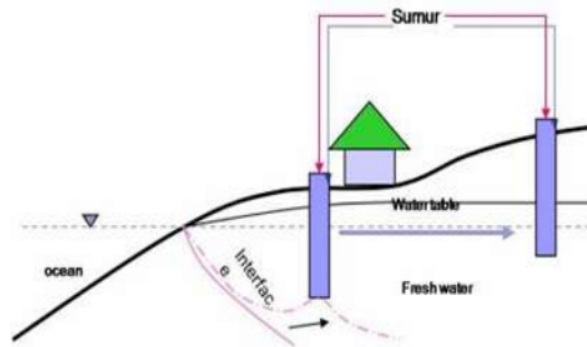


Figure 3. Changing the Pumping Pattern.

2.2.2. Artificial groundwater recharge

Freshwater level in the aquifer is raised by artificial recharge as shown in the figure 4. For unconfined aquifers, it can be done by spreading water on the surface of the soil, whereas in the confines aquifer, it can be charged directly into the aquifer. In this research, the recharging water will be filling into the aquifer by placing the sand column in the recharge basin. This method has never been done either in the form of research in laboratory or application in the field.

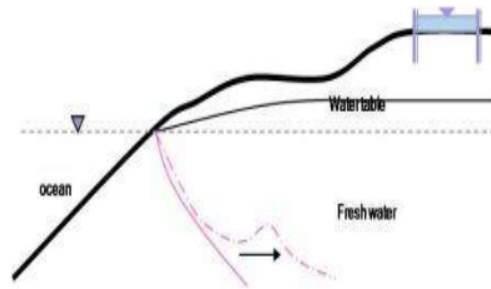


Figure 4. Artificial groundwater recharge

2.2.3. Extraction barrier

Extraction barriers as shown in figure 5 can be made by continuously pumping saltwater at wells located near the coastline. This pumping will lead to the occurrence of saltwater basin and freshwater will flow into the basin. As a result, there is a seawater wedge to the mainland.

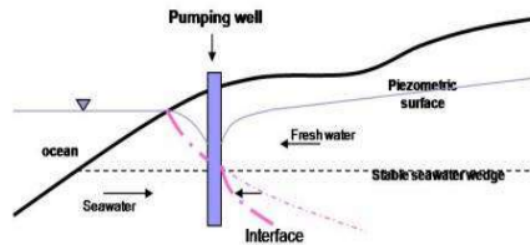


Figure 5. Extraction Barrier.

2.2.4. Injection barrier

Injection barriers as shown in figure 6 can be made by filling freshwater at wells located near the shoreline. Filling the water will raise the water table in the well and will serve as a barrier to the entry of seawater to the mainland.

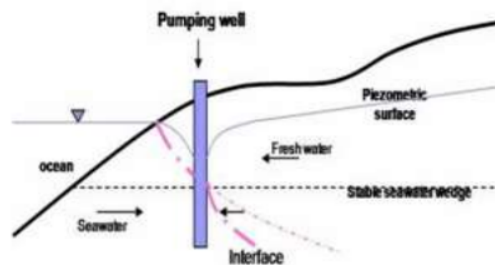


Figure 6. Injection Barrier.

2.2.5. Subsurface barrier

Barriers underground as a barrier between saltwater and freshwater as shown in figure 7 can be in the form of the dam, which is made from clay, concrete, bentonite or asphalt.

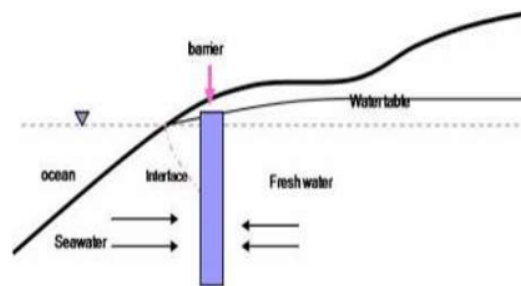


Figure 7. Subsurface Barrier.

2.3. The model of recharge basin with sand columns

2.3.1 More complex tables

One form of artificial recharge is a recharge basin that has a primary function as a water absorption medium to easily and quickly enter the aquifer layer. This reservoir model is suitable for land with shallow groundwater and wide land available. The basic philosophy in the development of a catchment basin is how to minimize surface runoff and to improve soil's ability to absorb surface runoff. The creation of a catchment basin is different from the usual reservoir making. The recharge basin is made with a reservoir base connected directly with the aquifer layer. The recharge reservoir is essentially can be categorized as a single reservoir (single-purpose) which serves as a flood control system with employment increasing aquifer function optimization, which increases the ability of the shelf water in the aquifer layer.

The functions of recharge reservoir are:

- To optimize the aquifer function so that it can increase the shelf life of the water in the aquifer
- It can serve as flood control in the downstream area or runoff.
- As a reserve of water for the needs in the dry season.

The results of the study of the Ministry of Research and Technology in Indonesia which has been done since 2003 and it is known that the application of the technology of the infiltration reservoir is able to overcome the flood and drought that hit Indonesia every year. The rate of infiltration (infiltration rate) in the reservoir is quite high.

2.3.2 Physical models of the sand column

The sand column serves as a medium to absorb the water of the recharge basin into the aquifer layer. The sand column is made using a drill on a clay layer that has a small permeability and restocked with graded coarse sand. The sand must be watered without carrying fine soil particles.

Water from surface water is stored in reservoirs with a certain height. Then the water is streamed through sand columns in the hope that sand that has a value of the coefficient of large permeability, can accelerate and increase the occurrence of recharge, as well as filtration for water into the aquifer layer is in a clean state.

3. Methods of research

3.1. The technique of collecting data from the experiment model

This study uses a square test tube consisting of three spaces namely space A contains seawater that has been given a coloring substance with a size of 30 x 10 x 100 cm, space B contains sand with size 40 x 10 x 100 cm and space C which is recharge reservoirs using sand columns with size 80 x 10 x 100 cm Land that has been known to type and meet the permeability requirements, put into the tub, then made

the sand column. On the surface of the basin are given debit entries freshwater (Q1) and the flow of seawater (Q2) each with a height of a particular water, at the time the land has undergone a water-saturated (saturated), seawater by substances dyes, then performed the measurement length of freshwater pushes seawater (L) in room B containing crushed stone each 3 variations for water level in the reservoir of reservoir (H2) of 5; 7.5; 10 cm, sand column height (Z) of 30; 32.5; 35 cm and the number of sand columns (Nc) of 0; 2 and 4 pieces. Sea level (H1) is fixed to 50 cm.

3.2. The technique of collecting data from the numerical model

This study uses the numerical modeling of SEAWAT to investigate the effectiveness of sand columns on the recharge reservoir to control SWI under laboratory scale [5,6]. The domain of the numerical model, namely in the form of two models dimensional rectangular size with assumption sea in the left and reservoir recharge in the right of the model. Land of known type and eligible permeability, as aquitard layer, then made as a sand column. On the surface of the basin are given a debit entry (Q1) and the seawater flow rate (Q2) each with a certain water level. At the time the soil has become water-saturated and happen equilibrium between seawater and freshwater in the aquifer system, further measured the length of freshwater pushing the seawater (L) in the aquifer of each 3 variations for the water level in the infiltration reservoir (H1) of 5; 7.5; 10 cm, sand column height (Z) of 30; 32.5; 35 cm and the number of sand columns (Nc) of 0; 2 and 4 pieces.

4. Expected results

1. From numerical modeling results, it expected that the effectiveness of sand column sand controlling SWI can be determined.
2. The number of sand columns will increase the freshwater pressure in the aquifer and will reduce the SWI.
3. Results of numerical modeling can be beneficial to explore the role of water level above the reservoir and the thickness of the impermeable layer in influencing SWI. This is supported by the results of previous studies by Azis (2014), which states that each additional column of sand and water level of reservoirs as well as lower impermeable layer will increase the discharge of groundwater recharge into the aquifer.
4. The results obtained from the experimental and numerical modeling is expected the same with a maximum deviation of 20%.

1 Acknowledgments

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