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The Use of Sand Column in Recharge Reservoir to Reduce Sea Water Intrusion

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Abstract. Excessive groundwater extraction, causing the occurrence of water loss under the surface of the soil, causes the sea water pressure to land larger, resulting in sea water intrusion. To overcome seawater intrusion, one way that can be done is by adding groundwater using a sand column placed at the bottom of the recharge reservoir which connects directly to the aquifer layer. The purpose of this study was to analyze the effectiveness of using sand columns in recharge reservoirs as a buffer for sea water intrusion. This research is a numerical modeling study using SEAWAT program simulation, which will produce data in the form of sea water intrusion. Parameters used are: the number of sand columns, isochlor concentration, where each parameter consists of 3 variables and the reservoir water level is 8 variables. The simulation results obtained show that by increasing the number of sand columns and reservoir water height, the length of seawater intrusion can be shortened.by using of three sand columns and reservoir water level of 97 cm, the results show a decrease of 2281.05% compared to those without using a sand column.

INTRODUCTION

Excessive extraction of groundwater for meeting the needs of the community and for commerce activities has made the underground water void below the surface, resulting in sea water intrusion (SWI) (Herlambang and Indriatmoko, 2005, Badaruddin S. et al., 2015; 2017; 2018). Under natural conditions, groundwater flows to the sea. The density of salt water is slightly higher than that of fresh water. Thus, the sea water will push the fresh water in the soil more inland. Therefore,if the high groundwater piezometric pressure is higher than sea level, the pressure can be neutralized and a balance between sea water and groundwater occurs and sea water intrusion can be prevented (Putranto and Kusuma, 2009). The process of intrusion can occur if the extraction of groundwater is done excessively (Herlambang and Indriatmoko, 2005). According to Hargono (2011), if the intrusion has entered the well, the well water will become salty so that it can no longer be used for daily needs. To overcome this, artificial SWI recharge can be done by using infiltration reservoirs that have the ability to absorb surface flow compared to pond which functions as a water storage. The infiltration reservoirs are designed to reach the aquifer layer (Azis, A. 2015). However, there is a problem. If the recharge reservoir is in an area which has small permeability value and low absorption, the water which reaches the aquifer layer will be slow so that its function as a recharge reservoir cannot be achieved (Hardiyatmo, 2010). To overcome this problem, we examined the use of a sand column model which is placed at the bottom of the infiltration reservoir. It is directly related to the aquifer layer with several parameters that can increase the water flow entering the aquifer layer. Based on these aspects, this study aims to determine the effectiveness of the use of sand columns in infiltration reservoirs for seawater intrusion using numerical models. This research contributes to the development of infiltration reservoirs, which become an alternative solution to prevent seawater intrusion.

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Sea Water Intrusion

Ground water has an important role as a natural resource which supplements surface water. It has natural supply, relatively constant quality, and relatively low investment costs. The utilization can be done in places that need it. Communities, both individuals and groups, need water for their daily needs and also for other needs. From various types of needs, drinking water is a top priority, compared to other needs. This means that the function of water for drinking must be fulfilled and the quality and quantity of water must be maintained. Water is used for the needs of living things. Considering the important role of groundwater, the use of groundwater must be based on the balance and preservation of underground water by filling water into the ground, both natural and artificial.

Coastal zone is a region topographically in the form of a lowland and morphologically in the form of a coastal plain. Geologically, the constituent rocks are generally in the form of alluvial SWI deposits consisting of clay, sand and gravel resulting from the transport and erosion of rocks in the upper part of the river. Generally, the rocks in the plain are loose. So, the potential of groundwater is quite good. The main problems in the coastal zone are the diversity of aquifer systems, the position and spread of sea water intrusion due to the extraction of groundwater for the needs of fishermen and industry.

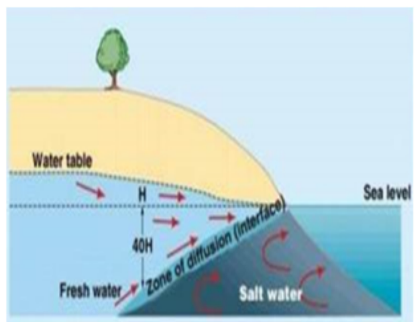
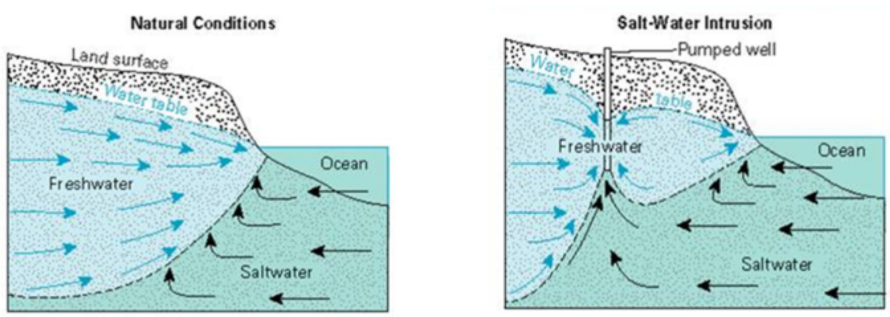


FIGURE 1. Cross Section of the Meeting of Groundwater and Sea Water

Naturally seawater cannot enter far into the land because groundwater has piezometric which presses stronger than sea water, so an interface is formed as the boundary between groundwater and sea water. This situation is an equilibrium condition between sea water and groundwater.



(a) (b)

FIGURE 2. (a) Condition of (a) Natural Interface and (b) Experiencing Intrusion

Infiltration of seawater into the aquifer system passes through two systems, namely sea water intrusion and up coning. Sea water intrusion in coastal areas is a process of infiltration of salt water from the sea into groundwater on land. The meeting zone between salt water and fresh water is called an interface. In natural conditions, groundwater will flow continuously to the sea. The density of salt water is slightly greater than the density of fresh water. So, the sea water will push the fresh water in the soil more upstream. However, because the high piezometric pressure of groundwater is higher than the sea level, the pressure can be neutralized and the water flow that occurs is from the marine land. Thus, a balance between sea water and groundwater occurs, so that sea water intrusion does not occur. Seawater intrusion occurs when the balance is disturbed. Activities that cause sea water intrusion include groundwater extraction through excessive pumping, coastal characteristics and constituent rocks, the strength of groundwater flowing to the sea, and groundwater fluctuations in coastal areas. If the intrusion has entered the well, the well will become salty so that it can no longer be used for daily needs.

According to the Ghyben - Herzberg concept, salt water is found at a depth of 40 times the groundwater level above the sea level. This phenomenon is caused by differences in density between sea water (1.025 g / cm3) and specific gravity of fresh water (1,000 g / cm3).

$$z = \frac{\rho f}{\rho s - \rho f} hf$$

so that the value of z = 40 hf is obtained

information:

hf = groundwater level above sea level (m)

z = interface depth below sea level (m)

ρs = specific gravity of sea water (g / cm3)

ρf = density of fresh water (g / cm3)

Upconning is the process of increasing the interface locally due to pumping in the well located just above the interface. When pumping starts, the interface is horizontal. The interface rises until it reaches the well. If pumping is stopped before the interface reaches the well, the sea water will remain in the position rather than returning to its original state. The higher the value of the ratio, the greater the effect of sea water intrusion is. Whereas if the ratio is low, the influence of sea water intrusion is small.

Seawater intrusion causes widespread losses especially for environmental aspects because it has the potential to change the nature and content of chemical, biological, and groundwater physics. Recognizing that intrusion is one aspect of the source of disasters, this study of intrusion is important (Dökmen, 2012; Felisa et al., 2013)

To control sea intrusion, there are several ways that can be done, among others;

1. Change the Pumping Pattern
2. Artificial SWI groundwater filling
3. Extraction Barrier
4. Injection Barrier
5. Subsurface Barrier

The recharge reservoir model uses a sand column

The function of the recharge reservoir.

One form of artificial recharge is infiltration reservoirs that function as a water infiltration medium to easily and quickly enter the aquifer layer. This model of reservoir is suitable for land with shallow groundwater and extensive land. The basic principle in the development of recharge reservoirs is how to minimize surface runoff and increase the ability of the soil to absorb surface runoff. Making infiltration reservoirs is different from making normal reservoirs. The base of infiltration reservoir is connected directly to the aquifer layer. Infiltration reservoirs can essentially be classified into a single purpose reservoir, which functions as a flood controller by increasing the optimization of aquifer functions, that is increasing the water retention ability in the aquifer layer.

According to Azis (2014a), the uses of recharge reservoirs are:

1) optimizing aquifer functions so that it can increase the water retention power in aquifers;
2) functioning as a flood controller in the downstream area or runoff;
3) functioning as a water reserve for needs in the dry season.

Physical Model Using Sand Columns

The sand column is functioned as a medium to absorb the reservoir water into the aquifer layer. The method of making a sand column is to make a hole using a drill in a clay layer that has small permeability and replenish it with coarse graded sand. The sand must be drained without carrying fine soil particles.

Water from surface water is accommodated in reservoirs with a certain height. Then, the water is flowed through the sand columns so that the sand has a large permeability coefficient value, can accelerate and enlarge the occurrence of recharge, as well as a filtration so that the water entering the aquifer layer is clean. (Azis, 2014a)

Numerical Method

To predict the length of the SWI, 2D (two-dimensional) modeling is used by employing the SEAWAT program for flow with variations in density and transport of solutions. This program uses a finite difference method that can be used only for streams saturated with water. The description of the numerical method and the equations used in SEAWAT can be seen in Guo and Langevin (2002) and Langevin et al. (2008).

RESEARCH METHODS

This study uses SEAWAT modeling in order to examine the effectiveness of sand columns at recharge reservoirs in preventing seawater intrusion. SEAWAT has been validated by several benchmarks such as Henry and Elder Problem (Guo and Langevin, 2002; Langevin et al., 2008; Badaruddin. S, et.al., 2017; Badaruddin. S, et.al., 2018).The domain of the numerical model is shown in Figure 3 1, which is a two-dimensional model rectangular in size with the assumption that the sea is on the left and the recharge reservoir is next to the model. Soil from Sudiang, city of Makassar that is known to be of type and meets permeability requirements, as an aquitard layer, then made a sand column.The distance between the sand column and the beach is 53 cm. On the surface of the body, the input flow (Q1) and the flow rate of sea water (Q2) are each given a certain water level. When the soil is saturated and there is equilibrium between sea water and fresh water in the aquifer system, then measurements of freshwater length are carried out by pushing sea water intrution (L) in an aquifer, each of 3 variations for the water level in the recharge reservoir (Hw) and the number of sand columns.The numerical model using SEAWAT has been used previously by other researchers and has been validated as done by Badaruddin. et.al (2015) by comparing the results obtained from SEAWAT numerical models and physical models in simulating Water Table Salinization.

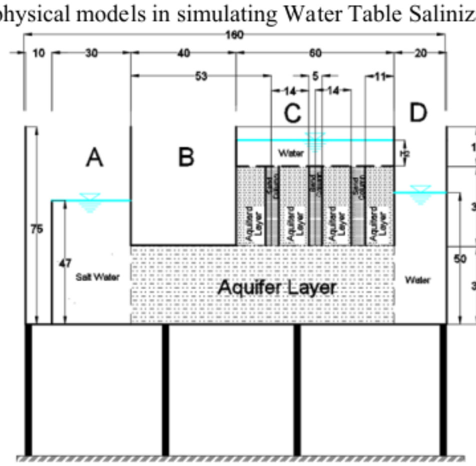


FIGURE 3. The concept of seawater intrusion models uses recharge reservoir with sand columns

RESULTS AND DISCUSSION

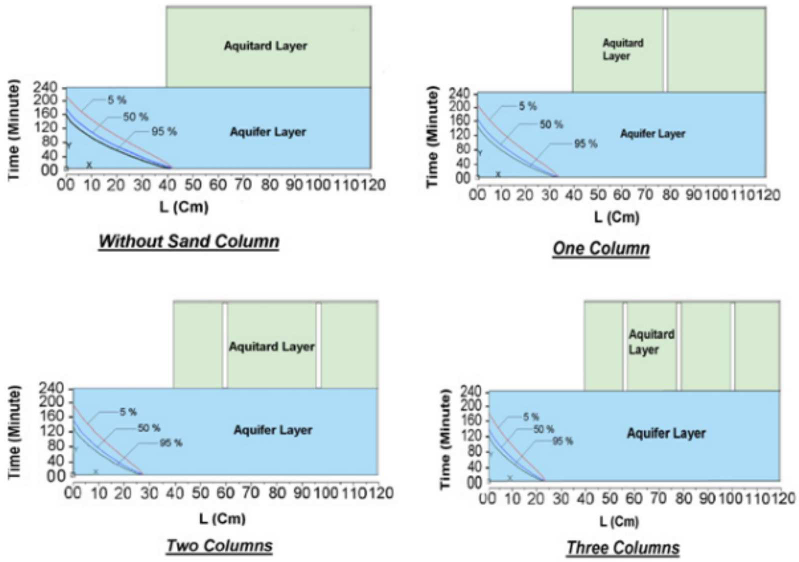


FIGURE 4. Length of Sea Water Intrusion in Various Amounts of Sand columns

Figure 4. is one of the simulation results from the SEAWAT program with a variable number of sand columns (Nsc), reservoir water level (Hw), and isochlor concentration. Based on the picture, the length of sea water intrusion was then measured.

The effect of the number of sand columns on the length of sea water intrusion

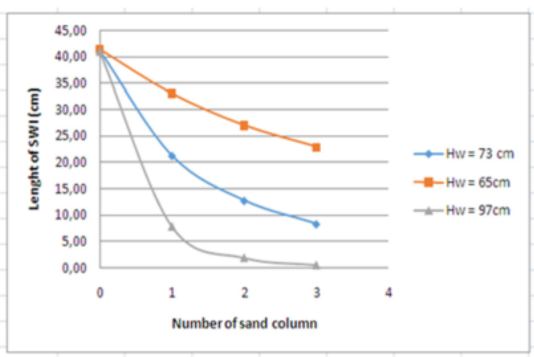


FIGURE 5. Effect of the number of sand columns on the length of sea water intrusion

As Figure 5. indicates, without a sand column, the sea water intrusion is flowing to land longer than if a sand column is given. In the use of one sand column there was a decrease in the length of sea water intrusion by 20.21%, two sand columns of 43.69% and three sand columns of 68.82% in the reservoir height (Hw) = 68 cm. At the reservoir surface height (Hw) = 73 cm, using one sand column, there was a decrease in the length of sea water intrusion by

48.27%, two sand columns at 133.45% and three sand columns at 257.84%. Meanwhile, at the height of reservoir (Hw) = 97 cm, using one sand column, there was a decrease in sea water intrusion length of 81.06%, two sand columns of 505.16% and three sand columns of 2281.05%. This is in accordance with the results of Azis research (2014b) which indicates that there is an increase in water flow into the aquifer layer as the number of sand columns increases. The increase of fresh water in the soil will increase the piezometric which suppresses seawater stronger and is able to shorten the occurrence of seawater intrusion. Then, the interface is formed as the boundary between groundwater and sea water. The multiplication of aquifers through a column of sand increases the pressure of freshwater capable of driving sea water intrusion.

Effect of reservoir water level on the length of sea water intrusion

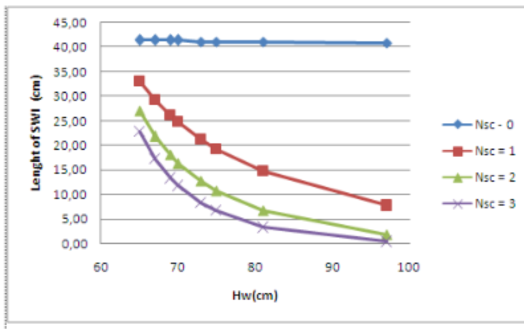


FIGURE 6. Effect of reservoir water level on the length of sea water intrusion

As Figure 6. indicates, the increase in reservoir water level (Hw) affects the length of specSWI seawater intrusion using sand columns (Nsc = 1, Nsc = 2, Nsc = 3), while those not using sand columns (Nsc = 0) do not change significantly. As the results of Azis research (2014b) show, there is an increase in water discharge into the aquifer layer as the reservoir water level increases. The higher the water level of the reservoir, the greater the pressure of water that enters the aquifer through the sand column so that it is stronger in encouraging sea water intrusion.

In one sand column, the addition of Hw = 65 cm to Hw = 67 cm will cause a decrease in the length of sea intrusion by 11.49%. Addition of from Hw = 65 cm to Hw = 69 cm will cause a decrease in the length of sea intrusion by 23.56%. Addition from Hw = 65 cm to Hw = 70 cm will cause a decrease in the length of sea intrusion by 31.68%, while the addition from Hw = 65 cm to Hw = 73 cm will cause a decrease in the length of sea intrusion by 47.63%. Addition from Hw = 65 cm to Hw = 75 cm will cause a decrease in the length of sea intrusion by 64.78%, while additions from Hw = 65 cm to Hw = 81 cm will result in a decrease in the length of sea intrusion by 94.84% and additions from Hw = 65 cm to Hw = 97 cm will cause a decrease in the length of sea intrusion by 171.44%.

Whereas in two sand columns, the addition of Hw = 65 cm to Hw = 67 cm will cause a decrease in the length of sea intrusion by 19.34%. Additions from Hw = 65 cm to Hw = 69 cm will cause a decrease in the length of sea intrusion by 40.61%. Additions from Hw = 65 cm to Hw = 70 cm will result in a decrease in the length of sea intrusion by 58.76%, while the addition from Hw = 65 cm to Hw = 73 cm will cause a decrease in the length of sea intrusion by 87.35%. Additions from Hw = 65 cm to Hw = 75 cm will cause a decrease in the length of sea intrusion of 127.61%. Additions from Hw = 65 cm to Hw = 81 cm will cause a decrease in the length of sea intrusion by 188.72% and from Hw = 65 cm to Hw = 97 cm will cause a decrease in the length of sea intrusion by 375.82%.

In three sand columns, the addition of Hw = 65 cm to Hw = 67 cm will cause a decrease in the length of sea intrusion by 24.41%, additions from Hw = 65 cm to Hw = 69 cm will cause a decrease in the length of sea intrusion by 55.24%. Additions from Hw = 65 cm to Hw = 70 cm will cause a decrease in the length of sea intrusion by 83.13%, while the addition from Hw = 65 cm to Hw = 73 cm will cause a decrease in the length of sea intrusion by 123.62%. Additions from Hw = 65 cm to Hw = 75 cm will cause a decrease in the length of sea intrusion by 195.09%, addition from Hw = 65 cm to Hw = 81 cm will result in a decrease in the length of sea intrusion by 292.29% and addition from Hw = 65 cm to Hw = 97 cm will cause a decrease in the length of sea intrusion by 685.76%.

CONCLUSION

Based on the simulation results using the numerical program SEAWAT, it can be concluded that the higher the reservoir water (Hw) and the number of long sand columns (Nsc),the shorter the intrusion of sea water towards the land is due to the encouragement of freshwater from the absorption reservoir through the sand column . Meanwhile, the greater the concentration of isochlor, the longer the intrusion of seawater toward the land is due to the reduced pressure of freshwater from the infiltration reservoir.

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REFERENCES

1. Herlambang, A., Indriatmoko, R. H. 2005. Management of Groundwater and Sea Water Intrusion. Air Indonesia Journal, 2: 211-225
2. Putranto, T., Kusuma. 2009. Problems with Groundwater in the Urban Area. Jurnal Teknik, 30: 48 - 56
3. Hargono, B. 2011. Learning from Tambakboyo Reservoir in Yogyakarta to Overcome Water Resources Problems on Small Islands and Beaches. Proceedings of PIT XXVIIHATHI, Ambon
4. Azis, A. 2015. Water Turbidity Impact on Discharge Decrease of Groundwater Recharge in Recharge Reservoir. Procedia Engineering ISSN 1877-7058 Vol. 125 pp: 199-206
5. Hardiyatmo, H.C. 2010. Land Mechanics 1. Gajah Mada University Press, Yogyakarta
6. Dökmen, F. (2012). Salinity and Seawater Intrusion into the Ground Water. Indian Journal of Science and Technology, 5 (12): 72 - 77.
7. Felisa, G .; Ciriello, V. and Federico, V.D. (2013). Saltwater Intrusion in Coastal Aquifers: A Primary Case Study along the Adriatic Coast Investigated within a Probabilistic Framework. Water, 5: 1830-1847.
8. Azis, A, 2014a, A Novelty of Sand Column Coefficient From Physical Modeling and Calculation. International journal of Applied Engineering Research, 9 (15): 2995-3008.
9. Guo,W., Langevin,C.,2002. User's guide to SEAWAT: A computer program for the simulation of three-dimensional variable-density ground-water flow: USGS Techniques of Water Resources Investigations, Book 6, Chapter A7.
10. Langevin, C.D., Thorne, D., Dausman, A.M., Sukop, M.C., Guo, W., 2008.SEAWATVersion4:Acomputer program for simulation of multi-species solute and heat transport: USGS Technique sand Methods, Book6, Chapter A22
11. Badaruddin, S., A. D. Werner, et al., 2017. Characteritics of Active Seawater Intrusion. Jornal of Hydrology 551. 632-647
12. Badaruddin, S., A. D. Werner, etal., 2015. Water Table Salinization Due to Seawater Intrusion. Water Resources Research 51 (10). 8397-8408.
13. Badaruddin, S., Azis, A.,.Mutiara, I., 2018. Application of Analytical Model and Numerical Modeling for Prediction of Sea Water Intrusion in Jeneponto Regency. SNP2M.
14. Azis, A, 2014b, Performance Analysis of Sand Column in Recharge Reservoir. International journal of Engineering and Technology, 4 (10): 577-581

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