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Analysis of Anti-Intrusion of Saline Water Well Using Sunjoto's Method

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Abstract

Coastal area was a place which are occupied since the beginning of civilization movement caused by this place contain fresh water especially in the sandy beach. In this area fresh water can be exploited easily by swallow dug well. But in modern era, this place changes become dense population area and as a consequent the saline water intrusion occurs due to the extraction of fresh water. The saline water intrusion occurs in many places of Indonesia for example it reaches the area of Monas in Jakarta, the saline water intrusion in city of Merauke caused by the over drainage of swamp area. This problem occurs when groundwater storage decrease caused by the decreasing of rain water infiltration to the ground and the exploitation groundwater increases. According to Ghijben-Herzberg relationship that the border of saline water and fresh water will increase about 40 times of decreasing groundwater surface and as a consequent the groundwater storage changes become brackish or salty. This system was proposed as a model of anti-saline water intrusion well which was called 'Coastal Fresh Water Optimal Well' which was tested in Biak island, and they proved that this design is appropriate for the coastal area fresh water withdrawal but there is not computation of this system. In this paper the sustainability design can be analyzed using parameters of depth of fresh water storage and up coning. Up-coning depends drawdown and drawdown depends on discharge of pumping, coefficient of permeability of soil and shape factor of well.

Index Terms: *Discharge, Intrusion, Shape Factor, Up Coning*

I. INTRODUCTION

Anti- intrusion of saline water well hereinafter referred to as one word 'Well' constructed by Hantoro W.S. (2015) on a small island of coral reefs, carbonate sand, 1 ha wide, 30 cm thick layer of soil sand 3 m (Fig.1.). The main purpose of this well is for small island coastal communities to utilize fresh water that is accommodated in the coastal aquifer layer which generally has a thin fresh water thickness. To gain the fresh water in this area is not so easy because the saline water will move upward by up coning as a consequent of pumping. Then the well should be modified that inflow water is not from the bottom of the well but from the upper side of the wall well which is located as high the fresh water surface, so fresh water only can enter to the well. With this well, when the boundary between saline water and fresh water rises due to up coning follows the principle of Ghijben (1889) -Herzberg (1901), saline water does not necessarily enter the end of the pump pipe because it is blocked by the well wall. The problem is that this design has never been analyzed how much the maximum pumping discharge will continue to get fresh water to meet the daily needs of the community's domestic water. For this reason, this paper will generally analyze a well in the coastal aquifer about the relationship between pumping discharges, fresh water thickness, length of porous wall of well, diameter of well and the propose method to compute up coning to obtain a design its sustainability can be achieved that the fresh water only can be withdrawn. .

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1. Ghijben-Herzberg Relationship

In the era leading up to WWI in Europe relations between nations were not conducive due to political tensions between the entities of the nations before the war. Until the two researchers, such as Badon Ghijben (1889) from the Netherlands and Herzberg (1901) from Germany, the results of establishing the equation of the relationship of fresh water with salt water in the coastal areas on a circular sandy island and rain which is the source of fresh water which was finally stated by the world water community that the two researchers were the inventors of the method. The hydrostatic pressure on the point A is pA (Fig. 2) are:

$$p_A = \rho_s g h_s \qquad (1)$$

$$p_A = \rho_f g h_f \qquad (2)$$

Equation (1) = (2) so,

$$\rho_s g h_s = \rho_f g h_f \Rightarrow \rho_s h_s = \rho_f h_f$$

Finally, the equation will be:

$$\Delta h = h_s\left(\frac{\rho_s - \rho_f}{\rho_f}\right) \qquad (3)$$

where,

Δh: thickness of fresh water on top of sea level (h_f - h_s) (m)

h_s : thickness of saline water (m)

h_f : thickness *fresh water* (m)

ρ_s : saline water density (kg/m^3)

ρ_f : fresh water density (kg/m^3)

When saline water ρs = 1,025 kg/m^3 and fresh water ρ_f = 1,000 kg/m^3 therefore:

$$\Delta h = \frac{1}{40} h_s \qquad (4)$$

2. Up coning

Up coning is a phenomenon that occurs when an aquifer with two reservoirs is fresh water that is supported above saline water due to differences in water density. Changes in groundwater level in fresh water will greatly affect the dynamics of the boundary with saline water below. This can occur due to decreased groundwater supply from upstream, loss of surface puddles and a lot of it occurs due to pumping fresh water which causes an increase in the limit under the pump and as a consequent the boundary of saline and fresh water will move upward and it's called up coning. According to Todd (1980) the equation to calculate the up coning value is:

$$z = \frac{Q}{2\pi d K\left(\frac{\rho_s - \rho_f}{\rho_s}\right)} \qquad (5)$$

Based on the Forchheimer (1930) and Ghijben-Herzberg relationship can be implemented a proposed equation to compute value of up coning as follows:

$$z = \frac{Q}{FK\left(\frac{\rho_s - \rho_f}{\rho_f}\right)} \qquad (6)$$

where:

z : up coning (m)

Q : discharge of pumping (m^3/s)

F : shape factor tip of well (m)

K : coefficient of permeability of soils (m/s)

d : diameter of casing/wall of well (m)

ρ_s : saline water density (kg/m^3)

ρ_f : fresh water density (kg/m^3)

II. ANALYSIS

In this paper will be analyzed the relationship between up coning (z), pumping discharge (Q), shape factor (F) of well, coefficient of permeability (K). While the shape factor functions well diameter

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(D = 2rw), length of porous wall of well (L). In this calculation will be discussed about how is increasing of up coning (z) then the drawdown compared to the thickness of the fresh water minus the length of the porous wall of well (hf - L) (Fig.1). When z > (hf – L) theoretically saline water will enter the well. To prevent the above problem, it can be done by decreasing of pumping discharge, increasing the value of the shape factor. To enlarge the shape factor value, it must increase the length of porous wall of well or diameter. Increasing the length of porous wall of well downward is at risk of the possibility of faster saline water intrusion occurring into the well, but increasing the diameter of well it only adding a less significant value of shape factor as (Sunjoto, 2017):

$$F = \frac{2\pi L}{\ln\left[\frac{L+2r_w}{2r_w} + \sqrt{\left(\frac{L}{2r_w}\right)^2 + 1}\right]} \qquad (7)$$

The equation of shape factor for impermeable casing that water flow only from bottom of casing (Sunjoto, 2002) is:

$$F = 2\pi r_w \qquad (8)$$

where,

F : shape factor of well/casing (m)

L : length porous wall of well/casing (m)

r_w : radius of well (m)

The boundary between saline water and fresh water is not a line but a transition field between the both, so to get pure fresh water, a safety factor is needed which is quite large with and according to Todd (1980) of 50% of up coning or save factor SF=1.50.

III. EXAMPLE OF COMPUTATION

For example, data of calculation are: diameter of well $D = 2r_w$ = 100 cm; length of porous wall of well L = 25 cm; fresh water thickness h_f = 3.75 cm; soil permeability K = 0.0047 m/s; saline water density ρ_s = 1,025 kg/m^3; and fresh water density ρ_f = 1,000 kg/m^3, and (h_f - L)= 3.50 m.

1, Pumping on the 'well'

When discharge of pumping Q = 0.10 m^3/min = 0.00166667 m^3/s, so:

• First step, compute shape factor [Eq. (7)]:

$$F = \frac{2\times\pi\times 0.25}{\ln\left[\frac{0.25+2\times 0.50}{2\times 0.50} + \sqrt{\left(\frac{0.25}{2\times 0.50}\right)^2 + 1}\right]} = 1.90m$$

• Second step, compute up coning value [Eq. (6)]:

$$z = \frac{0.0016667}{1.90\times 0.0047\times\left(\frac{1{,}025-1{,}000}{1{,}000}\right)} = 7.47m$$

With save factor SF=1.50 so:

In this condition the saline water will flow to the well easily, therefor value z should be decreased therefor the discharge becomes Q = 30 l/minute = 0,0005 m^3/s.

$$z = \frac{0.0005}{1.90\times 0.0047\times\left(\frac{1{,}025-1{,}000}{1{,}000}\right)} = 2.24m$$

• Third step, compute up coning value using modified discharge Q = 0,0005 m3/s [Eq. (6)]:

So, the discharge Q = 30 l/minute is appropriate for the hydrogeologic condition and the dimension of the well.

2. Pumping without 'well'

- • First step, compute shape factor of casing where diameter D = 10 cm or r_w = 0.05 m [Eq. (8)]:

$$F = 2\times\pi\times 0.05 = 0.314m$$

- Second step, compute up coning value using discharge Q = 30 l/minute = 0,0005 m^3/s [Eq. (6)]:

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$$z = \frac{0.0005}{0.314 \times 0.0047 \times \left(\frac{1{,}025 - 1{,}000}{1{,}000} \right)} = 13.554m$$

The up coning found in this condition is much bigger compared to (h_f – L) = 3.50 m and the intrusion of saline water to the well will occur.

CONCLUSION

This technique ('well') is appropriate to provide domestic water demand for population in coastal area of small islands and the method of analysis is easy to be implemented. For the next research should concentrate to the material of well which are saline resistant, durability, cheap in price and easy to be placed.

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