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Capillary Shock Phenomenon of Groundwater at the Beginning of Rainy Season

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***Abstract*—This study aims to determine the causes of decreased water level phenomenon that occurred in the early period of the rainy season. This phenomenon became anti-logic because when the rainwater has entered the soil surface layer, instead of groundwater in the saturated layer decreased (decline). This study is experimental field research conducted in Takalar. This research found that the phenomenon of decreased water level in the early period of the rainy season triggered by increasing of capillary pressure due to shrinking pore diameter after water began to infiltrate into the surface soil layer, i.e., the layer of the vadose zone. Increasing of capillary pressure caused the attraction of groundwater in the saturated zone to the vertical direction, so that the groundwater level has decreased significantly. Therefore, this phenomenon was called by the researcher as "capillary shock phenomenon." (2) The lowest groundwater level did not occur in the climax period of the dry season, but it happened in the early period of the rainy season. The phenomenon that took place during the climax of the dry season was the capillary pressure conditions in the lowest layer of the soil because soil pore diameter reached maximum conditions due to the high evaporation process. Groundwater pumping did not solely cause saltwater intrusion into fresh groundwater zone, but it also could be caused by groundwater decrease for each early period of the rainy season.**

***Keywords*— groundwater level; groundwater zone; saturated zone; *vadose* zone; capillary pressure; capillary shock.**

I. Introduction

The use of groundwater is higher along with increased needs resulting from population growth and an increase in the scope of human activities that need water. Besides, the limited sources of surface water more due to decreased vegetation density, and increasing land surface opened due to the use of land for agricultural needs. The issue about the threat of groundwater crisis in the future is not just a threat slogan. The groundwater crisis is already widely experienced in various countries that have exploited groundwater exceeds the soil infiltration capacity. The Form of soil water crisis is not only in the form of groundwater degradation but also in the form of increased salinity of groundwater resulting in groundwater is no longer used. The threat of saltwater intrusion into freshwater basins is very prone to a coastal region, where people actively exploit groundwater, such as the location of the study conducted by the researcher in Takalar regency, South Sulawesi province. Therefore, in the use of groundwater to fulfill a wide range of human needs, it should be coupled with adequate knowledge and understanding of the characteristics and natural features of groundwater.

The groundwater is water under the ground surface that fills the cavities of the soil and rocks. The movement of groundwater by a capillary of the groundwater level to the top can be a significant source of water for plant growth. The entry process of water from the soil surface into the soil is called infiltration. Meanwhile, the movement of water in the soil because of gravity is called percolation. The ground at a certain depth saturates with water that is called groundwater. The depth of groundwater predicted based on groundwater levels are always experienced periods of rising and fall according to seasonal conditions or other factors outside environment.

The groundwater consists of hygroscopic water, capillary water, and gravity water. The hygroscopic water is water on the surface of the soil grains and cannot move significantly by the force of gravity or capillarity. The capillary water is that is part of the surplus of hygroscopic water in the cavity of the ground and restrained by gravity in the soil so that the drained water is unblocked. While the gravity water is part of the excess water hygroscopic and capillary that is ready to move out from the soil particles if the excellent drainage is available. The research conducted due to an unusual phenomenon observed by the researcher when conducting this research to investigate the effect of artificial recharge to groundwater recovery degraded. The researcher saw that the groundwater level at the early period of the rainy season decreased, with no pumping that was conducted by farmers. The decreased water level observed was quite significant because of the decline ranged between 50-80 cm, before returning increased after the intensity and frequency of rainfall are already high. The period of the phenomenon of this decreased water level can occur between 7-14 days since the farmers stopped pumping the groundwater. These times are long enough to allow salt water to get into the zone of fresh water in the subsoil.

II. Material and Method

A. Material

A chemist named Robert Boyle, states that when a capillary tube dipped in water; the water will rise higher inside the tube than the water is outside the tube [1]. Furthermore, some others like *Honoré Fabri* [2] and Jacob Bernoulli [3] state that fluid rises in the capillaries because air cannot get into the capillary tube as quickly as a liquid, so the air pressure is lower inside the capillary tube. While, others like Isaac *Vossius* [4], Giovanni Alfonso Borelli [5], Francis Hauksbee [6], and Josia Weitbrecht [7], reveal that the liquid particles are attracted to each other and attached to the wall in the capillary tube. Jurin observed that the height of fluid in a capillary column was a function of the cross-sectional area at the surface, not of any other dimensions of the column [6], [8]. From this observation, Jurin formulated the height of a liquid column given by Jurin's Law. Then, in 1805, two researchers, i.e., Thomas Young (England) and Pierre Simon Laplace (Francis) succeeded in formulating a capillary action equation called Young-Laplace Equation [9]. Furthermore, Jurin's Law and Young-Laplace formula inspired much of the next inventor, Carl Friedrich Gauss (Germany) discovered the theory for determining the boundary condition that governs capillary action [10]. Lord Kelvin (England) discovered the effects of rats on the vapor pressure of liquid formulated in the formula Kelvin equation [8]. Franz Ernst Neumann (Germany) found an interaction between two non-mixed liquids [11].

Jurin's law formulated with the assumption that in a sufficiently narrow tube of circular cross-section (radius a), the interface between two fluids forms a meniscus that is a portion of the surface of a sphere with radius R. The pressure jump across this surface is:

$$\Delta p = \frac{2\gamma}{R} \text{ moreover,} \tag{1}$$

$$R = \frac{a}{Cos\alpha} \text{, then} \tag{2}$$

$$\Delta p = \frac{2\gamma.Cos\alpha}{a} \tag{3}$$

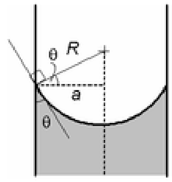

Fig. 1 Spherical meniscus with a wetting angle of less than 90°

Maintaining the hydrostatic equilibrium, the induced capillary pressure balanced by a change in height, h, this can be positive or negative. The changes depend on whether the wetting angle is less than or greater than 90°. For a fluid of density ρ and g is the gravitational acceleration:

$$h = \frac{2\gamma.Cos\alpha}{a.\rho.g} \tag{4}$$

The Young–Laplace Equation shares the force discrepancy to the form of the outside. Also, Young–Laplace Equation is primarily vital on stagnant capillary surfaces. The formula of Young-Laplace equation, $\Delta p = -\gamma.\nabla.\check{n}$ and $\Delta p = 2\gamma.H$ is as follows:

$$\Delta p = \left(\frac{1}{R_1} + \frac{1}{R_2}\right) \tag{5}$$

Where :
Δp: the pressure difference across the fluid interface,
γ: the surface tension (or wall tension),
ň: the unit usual pointing out of the surface,
H: the mean curvature,
R1, R2: the maximum radius of curvature.

Usually, for an open surface and "over-pressure," Δp at the interface in equilibrium creates a balance between the applied pressure, hydrostatic pressure, and surface tension effects. Thus, the Young–Laplace equation comes about:

$$\Delta p = \rho.g.h - \left(\frac{1}{R_1} + \frac{1}{R_2}\right) \tag{6}$$

The equation can be non-dimensionalised regarding its characteristic length-scale, the capillary length:

$$L_c = \sqrt{\frac{\gamma}{\rho.g}} \tag{7}$$

Moreover, characteristic pressure:

$$p_c = \frac{\gamma}{L_c} = \sqrt{\gamma.\rho.g} \qquad (8)$$

Capillary water in the soil is groundwater retained due to stronger cohesion and adhesion forces than the gravity force. Capillary water moves sideways or upwards due to capillary force. This capillary water occupies the micropore and macropore wall, held at a voltage between 1/3 - 15 atm (pF 2.52 - 4,20). Capillary water coats the ground granules, tied loosely by soil particles, can be released by rooting and can be absorbed roots.

Capillary pressure (Pc) defined as the pressure difference that exists between the surfaces of the two non-mixed fluids (liquid-liquid or liquid-air) as a result of the encounter of the surfaces separating them. This two-fluid pressure difference is the difference between "*no wetting phase*" fluid pressure (Pnw) and "phase wetting" (Pw) fluid, or:

$$P_c = P_{nw} - P_w \qquad (9)$$

Capillary pressure in porous rocks depends on the size of the pores and the fluid types. Quantitatively, it is in the quotation formula:

$$P_c = \frac{2\sigma.\cos\theta}{r} = \Delta\rho.g.h \qquad (10)$$

Where:
Pc: capillary pressure
σ: the surface tension between two fluids
cos q: surface contact angle between two fluids
r: pore-curved radius
Δρ: difference in density of two fluids
g: gravity velocity
h: column height

Capillary pressure has the critical influences in the fluid reservoir in the soil such as groundwater, oil, or gas, namely:

- Control the saturation distribution in the reservoir.
- It is the driving mechanism of oil and gas to move or flow through the reservoir pores in a vertical direction.

The capillary pressure may arise because of the pull of a thin layer of upper water surface due to the conflux between two different material types. In principle, the pull of the surface is the result of the difference in tensile forces between the molecules in the tangent plane of two different natural materials.

Due to the capillary pressure, the groundwater is attracted upwards over the surface and fills the space (pores) between the soil grains. Soil pores are not a capillary pipe system, but the capillary theory can be applied to study water reaction in capillary zones. The water in this capillary zone can be considered to be a negative pressure, i.e., having pressure under atmospheric pressure.

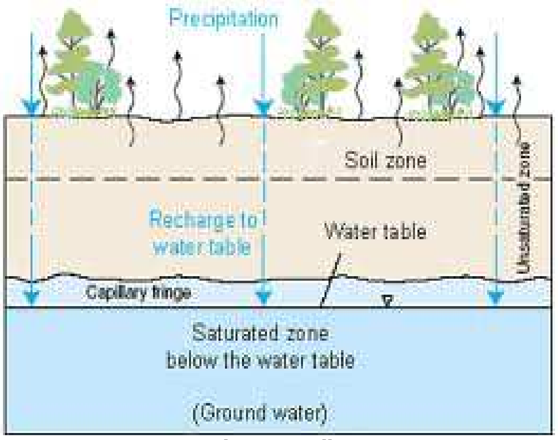

Fig. 2 Groundwater Capillarity Diagram

Capillarity diagram of a soil layer can be seen in Figure 1. The minimum height of hc (min) is affected by the maximum size of the soil pores. Within the boundary between hc (min) and hc (max), the soil may be partially saturated. Terzaghi, Peck, and Mesri gave an approximate formula between hc (max) and granular diameter [12], as follows:

$$h_c = \frac{C}{e.D_{10}}(mm) \qquad (11)$$

Where:
hc: High water in a capillary tube (mm)
C: Constants (C varies between 10-50 mm2)
D_{10}: Effective diameter (mm)
e: Soil pore number

Capillary water height for various soils mentioned by Hansbo [12], presented in Table 1

TABLE I
CAPILLARY WATER LEVEL

Types of soil	Landslide Condition	Solid Condition
Rough Sand	0.03 – 0.12 m	0.04 – 0.15 m
Medium Sand	0.12 – 0.50 m	0.35 – 1.10 m
Delicate Sand	0.30 – 2.00 m	0.40 – 3.50 m
Silt	1.50 – 10.0 m	2.50 – 12.0 m
Loam	-	> 10 m

If on the soil, it can be considered as a mixture of particles and pores, with pores forming a capillary tube;

$$F\uparrow = \sigma.\cos\alpha \times 2\pi.r \qquad (12)$$

where,
F↑ : upward force (N)
σ : surface tension of water against air (σ = 0.073 kg s^{-2} at 20°C)
α : contact angle of water with the tube (rad); (cos α = 1.0)
r : equivalent radius of the tube (m)

Due to the force of gravity, the water column of height C and mass πr2Cρ exerts a downward force (F↓), that opposes the capillary rise,

$$F\downarrow = \pi r^2 C\rho g \tag{13}$$

Where,

F↓ : downward force (N)
R : density of water (r = 1,000 kg/m3)
g : acceleration due to gravity (g = 9.81 m/s2)
C : height of capillary rise (m)

At equilibrium, the upward force (F↑), must equal the downward force (F↓). Hence,

$$\sigma.\cos\alpha.2\pi r = \pi r^2\, C.\rho.g \tag{14}$$

Then gives an equation for the height of the capillary rise,

$$C = \frac{2\sigma \cos\alpha}{\rho g r} \tag{15}$$

Some research results related to this study are such as MIKE SHE modeling [13]–[20]. The capillary gets higher comprises an ascending augment in the enduring disposable revitalize from 200 to 260 mm/Y [21]. Moreover, subsurface drainage reduces evaporation from waterlogged areas by an increase in stream flow that is one magnitude larger than the 2 mm / y decrease in aquifer replenishment. Vergnes et al. do the modeling with groundwater scheme implemented in the Total Runoff Integrating Pathways river-routing model in a previous study coupled with the Interaction between Soil Biosphere Atmosphere (ISBA) land surface model [22]. The upward capillary fluxes at the bottom of the soil increase the mean annual evapotranspiration simulated over the aquifer domain by 3.12% and 1.54% at high and low resolutions, respectively. This increase can locally reach 50% and 30%, respectively; (3) Xu, et al. conducted a study of the relationship between soil water level rise in agricultural land with a capillary rise in Hetao Irrigation Area (China) [23]. Results indicated that capillary rise rate increased as crop roots developed, averaging 2.3 mm d-1 during the mid-stage while groundwater set at 100cm deepness. The contribution of groundwater cropping growth was considerable when the distance downward of the groundwater table was fewer than 150cm but was irrelevant for depths over 200cm.

This research is quite specific because this study is not only conducted through field observation (not test model or computer simulation) but also because of this research oriented to the occurrence of groundwater degradation due to an increase of capillary water level in the soil, especially at the beginning of rainy season. It is very influential to farmers of groundwater users because many cases of irrigation are occurred wells vacuum in Takalar District, while rainfall has not been sufficient for water needs of plants at the beginning of the rainy season. Therefore, the information from this study is sufficiently desirable for the farmers who use groundwater, so that they can make irrigation wells that will not be affected by the decrease of groundwater due to the increase of capillary pressure, which the researcher termed as a capillary shock.

B. Method

This research conducted experimental field research by using 4 point test wells which have different conditions. The first well test placed in a location that without artificial recharge at all. The second ones placed on the point surrounded by artificial affix a pipe infiltration by 4 points. The third well surrounded by 8 points, and the fourth well surrounded by artificial recharge as many as 12 points. The fourth points of the test wells placed apart from each other at a distance from one another, ranging from 1-2 km. The procedure intended that the affixes that occur in one location not affect the groundwater level changes at other locations.

Each test well made with a depth of 8 m, which equipped with cashing wells from the 4-inch diameter of PVC pipe. The kind of soil layer was relatively same, which in the topsoil of soil layer (*vadose* zone) consists of organic sandy loam soil, and in the zone of the aquifer layer of soil (saturated zone) consists of the silt-sandy pebbly ground.

The research variables consist of three types, namely; (1) Rainfall (in order of rain or number of rain) as the independent variable, (2) The number of points added as an intervening variable, and (3) Fluctuations in groundwater levels as the dependent variable. The following scheme can describe this study design:

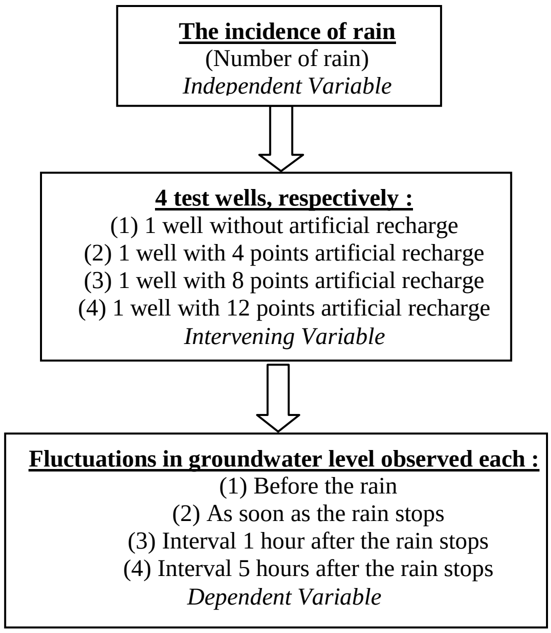

Fig. 3 Scheme of Research Implementation

Observations conducted until the phenomenon of decreased water level had stopped, and the tendency of the phenomenon began to occur the rise as a result of groundwater percolation process began to occur in the soil. The study only conducted to examine the phenomenon of decreased water level in the early period of the rainy season.

III. Results and Discussion

A. Results

This study provides some necessary information, which can be used to discuss the causes of the phenomenon of decreased water level in the early period of the rainy season. This information by the researcher has been summarized in the graph as illustrated below:

- The intensity of daily rainfall that occurred in the early period of the rainy season in Takalar, ranging from 5 to 22 mm as in chart-1 as described below.

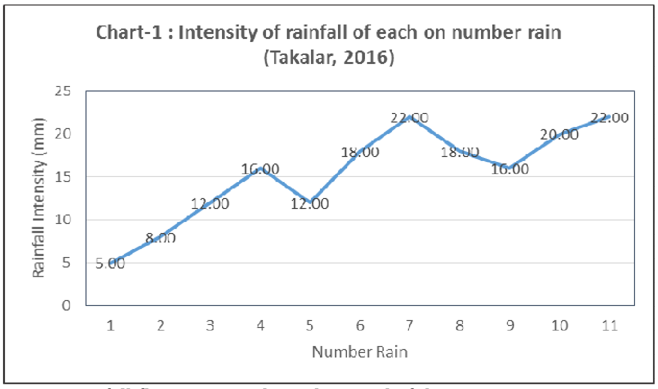

Fig. 4 Rainfall fluctuation in the early period of the rainy season on 2016

- With daily rainfall intensity levels mentioned above, it shows that it needs between 4 to 6 times in the rain to stop the phenomenon of decreased water level in the early period of rain.
- With daily rainfall intensity levels mentioned above, it indicates that it takes between 9 to 10 times to the rain to restore the level of the groundwater level that is equal to the position before the rainy season.

Both phenomena mentioned above can be seen in chart-2 to the chart-5 as described below.

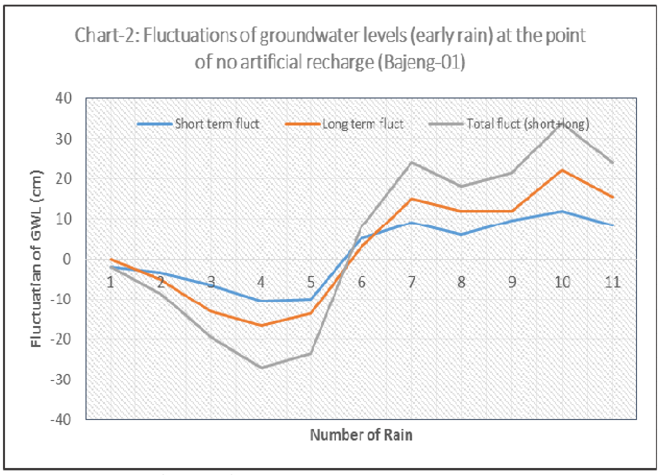

Fig. 5 Test well of no artificial rechange

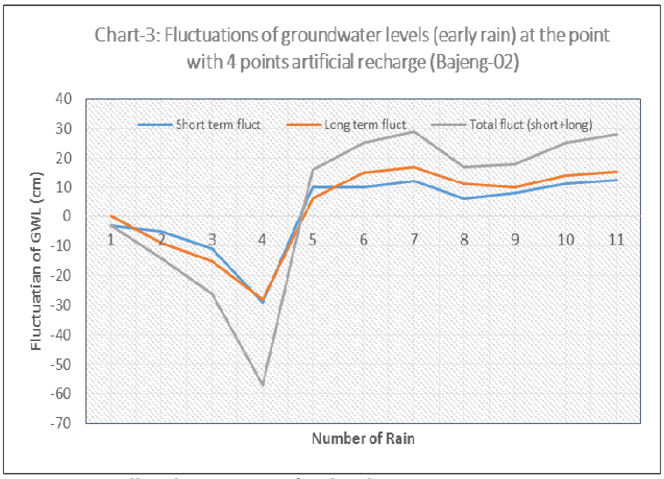

Fig. 6 Test well with 4 points artificial rechange

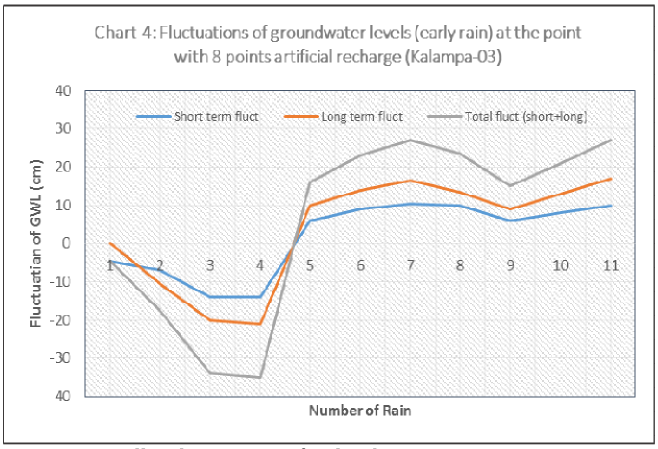

Fig. 7 Test well with 8 points artificial rechange

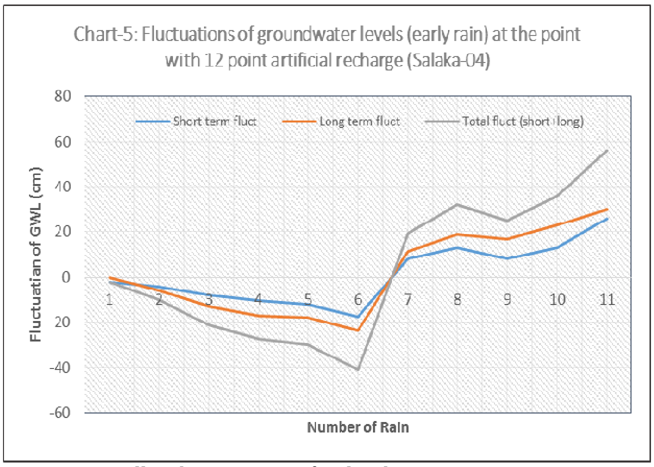

Fig. 8 Test well with 12 points artificial rechange

Figure 5, Figure 6, Figure 7, and Figure 8 showed the fluctuations of groundwater levels in early rain period.

- Scale-space groundwater level in the early period of the rainy season observed in all four test wells is quite varied (ranging from 50 to 80 cm). With the aim to see if there is the influence of the number of artificial recharge points placed around the well test, the researcher created the graph-6 as described below.

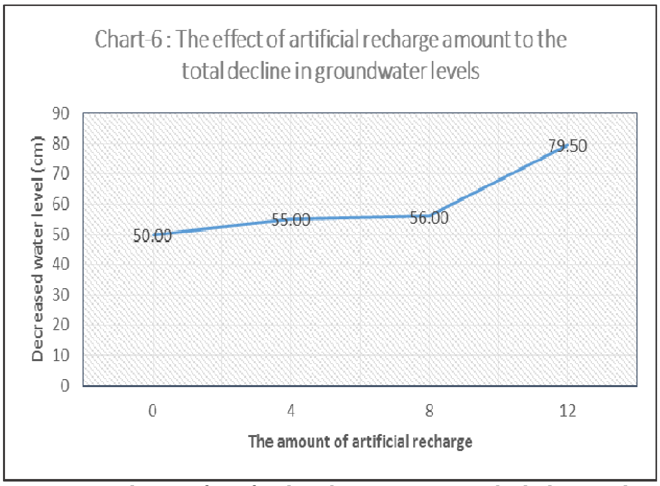

Fig. 9 Correlation of artificial rechange amount with decline total in groundwater

B. Discussion

Based on the research results that have described above, there are some critical issues to observe and discuss, such as:

1) Degradation of groundwater level in the early period of the rainy season: This issue is an exciting phenomenon to be studied because it not only showed the phenomenon of anti-logic that when the ground is getting a supply of rainwater instead of groundwater saturated degraded. However, also it is more than just a natural phenomenon; this phenomenon can impact the natural periods of saltwater to be an intrusion to freshwater

Zone when the groundwater level has decreased. This study's findings explain the various cases of seawater intrusion in coastal areas, where the locations not conducted groundwater pumping. It proves that the decreased in groundwater level was not only during the dry season, but it was faster and higher acceleration of the decline occurred in every period of the early rainy season.

To explain this phenomenon, the researcher explains some opinions. The decline of the groundwater table (saturated zone) which occurs during the dry season was naturally going down to the extent of soil layers that were not affected by evaporation due to higher temperatures on the surface of the ground. The water that can evaporate from the ground (evaporation) is only groundwater that is currently on soil water of *vadose* zone and the intermediate zone. The water in the capillary zone will be reduced due to enlargement of the pores in the surface soil due to drought. The assumption underlying the engineering foundations and geotechnical experts, when it needs information to predict the carrying capacity of the foundation or ground potential swelling, will use the level of the groundwater level at the top of the dry season. However, the findings of this study inform that the minimum level of the groundwater level does not occur at the height of the dry season, but it occurred in the early period of the rainy season. The illustration can explain this in the figure below:

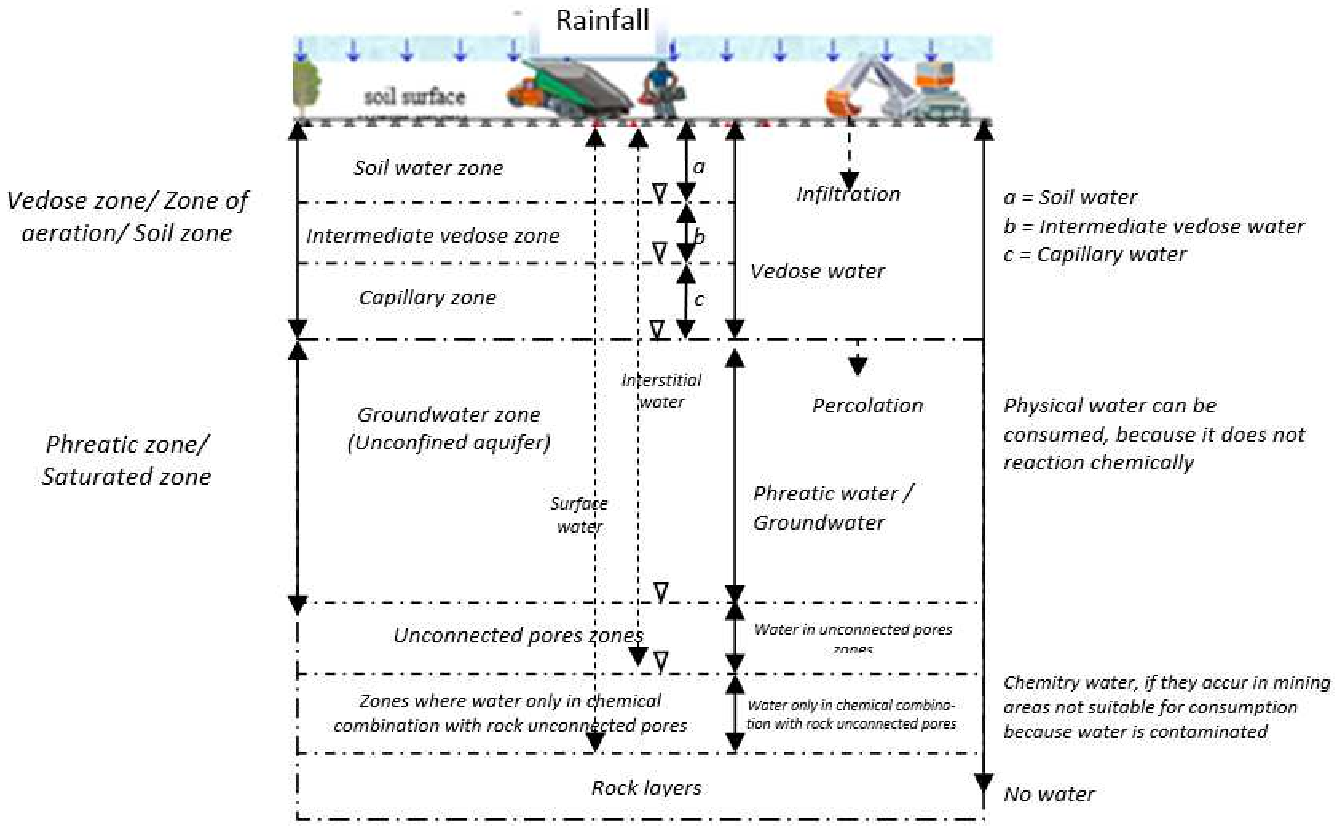

Fig. 10 The composition and the type of water in the subsoil

Capillary water that is between vadose zone and a saturated zone heavily influenced by the condition of the two layers that flank. The thickness of the capillary zone is highly dependent on the conditions of soil pores that are in the top layer. If the soil pores enlarged (dry season), the high-pressure capillary declined. Moreover, vice versa if the soil pores decline (the rainy season), the capillary pressure will be enlarged. This can be explained in the picture below:

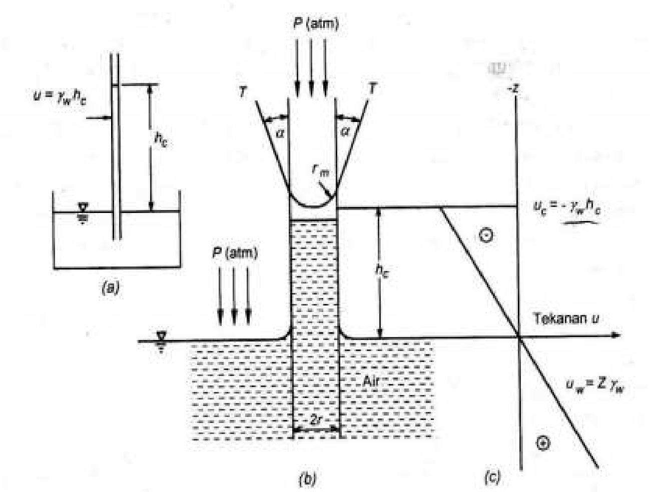

Fig. 11 The analogy of Capillary Water Pressure in Soil Layer and Its position (Holtz & Kovacs, 1981)

Based on the figure above, it describes that if hc is the height of the water within the capillary, d is the diameter of the pipe, γw is the weight of the volume of water, and the atmospheric pressure is taken as the reference area (air pressure is equal to zero). Holtz & Kovacs [23]), it can be formed vertical force equation at the height of the water column as follows:

In the situation of capillary water stops moving, then the weight of the column of water in the tube is:

$$W_w = 0{,}25.\pi.d^2.h_c.\gamma_w \quad (16)$$

While the number of vertical force due to the surface tension is:

$$F_{TSw} = \pi.d.T_s Cos\alpha \quad (17)$$

The requirement to balance situation is:

$$W_w = F_{TSw} \quad (18)$$

then:

$$0{,}25.\pi.d^2.h_c.\gamma_w = \pi.d.T_s.\cos\alpha \quad (19)$$

thus it is obtained:

$$h_c = \frac{4.T_s.\cos\alpha}{\gamma_w.d} \quad (20)$$

The pore water pressure (u) is negative that can be an analogy with the water pressure in the pipes that the water contained in the soil pores will be attracted or sucked by the differences in atmospheric pressure. The maximum pressure value is γwhc, which will take place at the height of capillary columns. The pressure distribution along the pipes can be seen in the picture-c above. The equation of the capillary pressure altitude (hc) in the pipeline is obtained by the substitution u = γw.hc and d = 2.r = 2.rm.cosα, in equation (3), will be obtained:

$$h_c = \frac{4.T_s.\cos\alpha}{\gamma_w.2r_m.\cos\alpha} = \frac{2.T_s}{\gamma_w.r_m} \quad (21)$$

$$u = \gamma_w.h_c = \gamma_w \frac{2.T_s}{\gamma_w.r_m} \quad (22)$$

$$u = \gamma_w.h_c = \gamma_w \frac{2.T_s}{\gamma_w.r_m} \quad (23)$$

$$u = \frac{2.T_s}{r_m} \quad (24)$$

The equation (3) and (4) prove that the value of hc and u will increase if the soil pore radius (r) is smaller (rainy season). Instead, hc and u will be reduced if the soil pore radius (dry season) is enlarged.

The phenomenon that follows the natural law which causes the groundwater level in the early period of the rainy season is always decreasing. The decrease is due to the diameter of the pore in the vadose zone layer decreases, thereby triggering an increase in capillary pressure in the soil, causing an increase in the thickness of the capillary zone is significant. Capillary water source, in this case, it is only one that is sucked/pulled from the water saturated soil (groundwater), so that it caused the groundwater level that will decrease in the acceleration process which is quite high. The researcher called this natural phenomenon as the "capillary shock phenomenon."

2) The relationship between the intrusions of seawater with the decreased water level in the early period of rain: In the coastal areas, the interaction between salt water and fresh water is always going to happen. The interaction areas both of them will always vary, depending on the balance of pore water pressure (u) between two zones occupied by the two types of water. Any difference in pressure that occurs in the interface both of them will soon be balanced. The water that has a more considerable pore pressure would shift the interface field towards the water which has a smaller pore pressure.

This phenomenon can be explained by the illustration as described below.

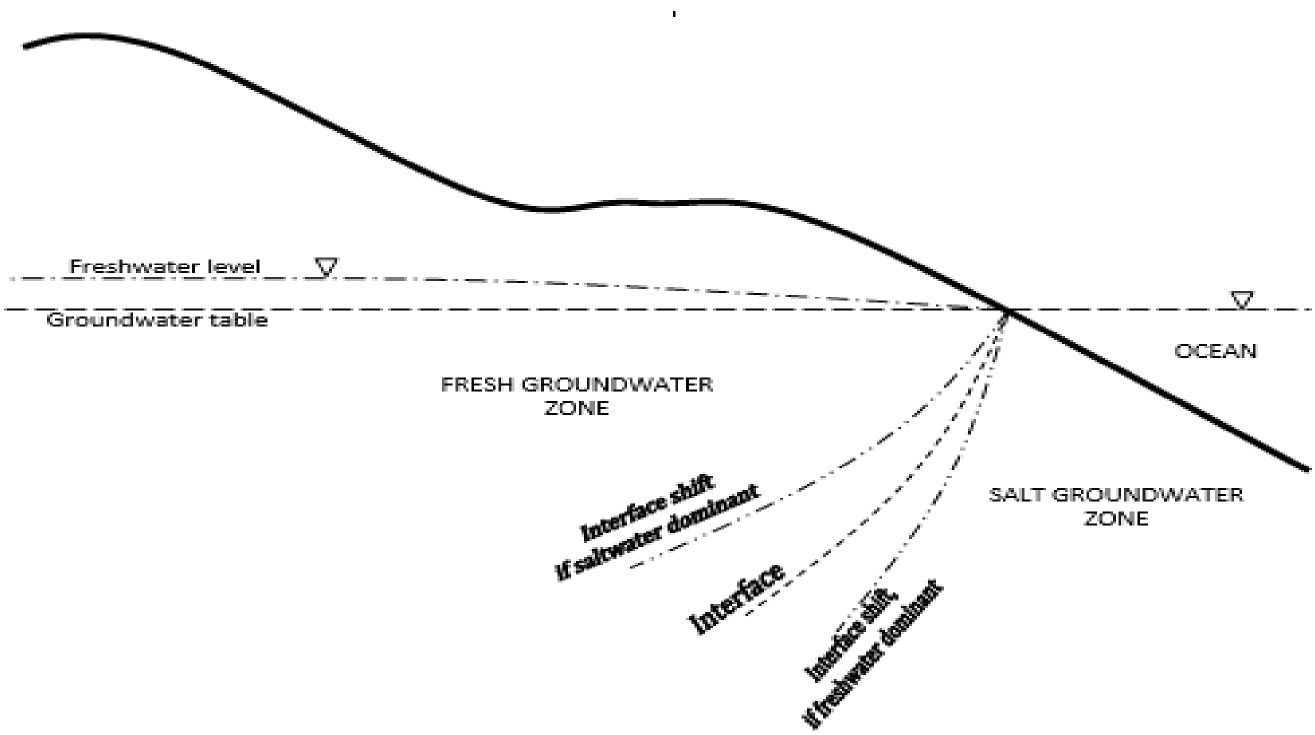

Fig. 12 The process of shifting interface between salt water and fresh water in various conditions in various conditions

From the figure above, it shows that the decreased water level fresh (freshwater table) due to groundwater attracted by capillary pressure in the early period of the rainy season, will cause the decrease of pore water pressure and make pressure dominant to the salt groundwater. This will have an impact on the shifting field of interface towards fresh groundwater zone. If the supply from the percolation process that occurs during the rainy season is not capable of causing more dominant pressure to the fresh water from salty pressure, then the field of the interface will not return to its original position. Therefore it causes a permanent saltwater intrusion. This phenomenon made some coastal locations continuously in the intrusion of sea water, even though groundwater pumping is not conducted because the condition of the ground has been broken so that it cannot support the process of infiltration and percolation of water into the layer saturated zone (groundwater).

3) The relationship between the number of artificial recharge points and the decreased groundwater level in the early period of rain: In conducting this study, it made four test wells, i.e., the first test well was to the conditions without an artificial recharge, 4 points, 8 points, and 12 points of artificial recharge. It was intended to see how the number of artificial recharge points to the total decline of groundwater, as well as to see its effect on the acceleration of the increase of groundwater level after the infiltration and percolation into the soil layer was effective. However, from the chart-6 which has been described previously, it has not been able to describe these two issues precisely. This may be due to the study design made yet able to reveal both the problems because the focus of this research is more focused on finding the causes of decreased water level in the early period of rain. For that both issues (the effect of some recharge points to the decline and increase of the groundwater level) require particular research design, to be implemented in future studies. Logically the presence of artificial recharge would affect the duration of the shock capillaries, and will also affect the payback period and increase the groundwater level during the rainy season.

4) Effects of soil particles to the decreased water level in the early period of rain: As we know that the diameter of pores of the soil strongly influenced by grain size and composition of the grain (particle composition) that are present in the soil. Therefore, the pore diameter serves as a capillary tube inside a layer of soil, and then both of these factors also affect the capillary pressure in the subsoil. Logically in finer soil particles that the smaller the diameter of the pore formed in the soil, the capillary pressure is higher. Thus, the thickness of the layer of capillary water on fine-grained soil is thicker than in coarse-grained soil (granular soil). In this study, the effects of soil particles as described above have not been implemented because it is difficult to condition the research in the field that allows the observation and measurement of the thickness of the layer of capillary water. Research on the influence of soil particles held in the form of experiments simulation in hydrology laboratory.

5) Effects of the vadose layer thickness of the decreased water level in the early period of rain: The capillary water layer is between the vadose zone and the saturated zone. Hence, the thickness of the layer of capillary water can be increased due to the reduced thickness of the saturated water layer (decreased water level), and by reducing the thickness of vadose zone (increase in capillary pressure). Therefore, fluctuations in the thickness of the water layer of capillary were affected by *vadose* layer, then by itself, *vadose* layer thickness also affected the duration of the process of capillary shock, and influenced the magnitude of the decline in groundwater levels due to the capillary shock. In this study, the influence of the thickness of the *vadose* layer has been unimplemented yet because it is difficult to condition the research in the field that allows the observation and measurement of the thickness of the layer of capillary water. Research on the influence of the thickness of the *vadose* layer also implemented in the form of experiments simulation in hydrology laboratory; they are carried out simultaneously with the research on the influence of soil particles to the decreased water level.

IV. CONCLUSIONS

Increasing capillary pressure triggered the phenomenon of decline in groundwater levels in the early period of the rainy season due to declining the pore diameter after the water level began to infiltrate into the surface layer of soil on the *vadose* zone. Increasing capillary pressure caused the attraction of the groundwater in the saturated zone in the vertical direction, so that the groundwater level has decreased significantly.

The low groundwater levels did not occur in the climax period of the dry season, but it happened in the early period of the rainy season. It took place at the top of the dry season was the capillary pressure conditions in the lowest layer of the soil. This was caused that the pore diameter reached the maximum condition, due to evaporation during the dry season.

Groundwater pumping did not solely cause the saltwater intrusion into fresh groundwater zone, but it also can be caused by subsidence of groundwater for each early period of the rainy season. If the decrease in groundwater level were not able to be recovered during the rainy season, hence the existence of saltwater into fresh groundwater zone would be permanent, and every year will increase. The low capacity of infiltration and percolation due to damage the surface soil layer also became one of the triggers of the saltwater intrusion.

The influence factor of the number of points added to the capillary shock capacity in groundwater needs to be further investigated. This is important because if it is true, the artificial recharge can contribute to shortening the time and capacity of the capillary shock, then the implementation of artificial recharge in prone areas affected by the intrusion will be a useful alternative solution.

The influence factor of the soil particles to the capillary shock capacity on the groundwater also requires the careful studies. It is also important because if this factor is affected by the duration and capillary shock capacity, they will help experts in manipulating the soil water conservation system, especially in efforts to prevent saltwater intrusion.

The influence factor of vadose soil thickness located above the capillary water level towards the capillary shock capacity also requires careful studies. This factor is important because if this factor is affected the duration and the capillary shock capacity, it is beneficial to those skilled in manipulating the soil water conservation system, especially in efforts to prevent saltwater intrusion and restoration of groundwater reserves in the free aquifers that are close to the ground.

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