Assessment of hydraulic conductivity improvement due to vibration application at riverbank

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Abstract. Groundwater abstraction is a process of obtaining subsurface water sources for variety purpose of consumption. However, due to long and continuous pumping, the efficiency might decrease because of soil clogging. This decrease can be quantified and reflected as the change of hydraulic conductivity (K) values at the pumping site. This study aims to assess the variability of soil hydraulic conductivity at groundwater pumping site and also to study the effectiveness of vibration method to improve the hydraulic conductivity by comparing the result of before and after vibration is applied. The study was carried out by measuring the K values using slug test at wells MW01 and MW02 with two durations of vibration which were 45 minutes and 60 minutes. The result shows that values of hydraulic conductivity of the soil were found to have increased for both MW01 and MW02 wells. On first trial, the hydraulic conductivity increases for MW01 and MW02 are 16.7% and 39.3% while on second trial, the percentage increases for MW01 and MW02 are 54.3% and 11.1% respectively. Although the change for MW02 decreased for 60 minutes vibration, it can still be noted as there is a positive impact of vibration to the K value and further extensive data collection will be able to provide better assessment. Thus, it has been proven that the vibration method can be effective in reducing the soil clogging effect and also able to improve the hydraulic conductivity of the soil.

1. Introduction

Water is one of the important elements responsible for life on earth. It flows through the surface or subsurface in various ways in order to transport, dissolve, replenish nutrients and organic matter and also carrying away wastewater. As such, a good and proper management of these processes, in particular the water supply, is the key element in ensuring the sustainability of water resources. There are numerous methods of water supply treatments available. Conventional treatment for water supply will use chemicals and complex machinery setup but for alternative treatment, the riverbank filtration (RBF) system will require less chemical treatment and can be cost-effective as well [1, 2]. The construction of the RBF system would involve less cost and can be considered as an effective treatment method for drinking water [3] which is widely used in many Asians and European such Germany, France, and Netherlands.

However, one of the challenges that is quite common for the RBF system is the presence of soil clogging. The effect of soil clogging may affect the process of filtration and reducing the value of hydraulic conductivity of the riverbank soil [4, 5]. This problem may arise if the riverbank filtration system operates in a long period amount of time. The use of conventional methods for well maintenance normally addresses the clogging issue surrounding the well only [6]. It is important to note that the clogging formation along the flow path due to the well pumping and the presence of colmation layer at
the riverbed is one of the reasons why clogging occur in the first place. Colmation can be defined as a process where fine particles such as silt and clay that is transported by groundwater become entrapped at the surface of aquifers [7]. These particles are low in permeability and have less porosity causing it to clog the streambed and affect the pumping efficiency.

The reduced hydraulic conductivity (K) due to fine sediments may cause the decrease of the flow velocity and quantity of water passing through the sediments and to the well. It is important to know the permeability of soil because the riverbed conductivity controls the volume of water filtrated through the system. The permeability of soil and hydraulic gradient need to be observed regularly in order to detect the presence of soil clogging. Very low hydraulic conductivity may affect the volume of bank filtrate while high or low value of hydraulic conductivity depends on the porous medium of the soil [8]. Soil texture comes in many forms for example gravel, sand, silt, and clay and generally the K values or hydraulic conductivity values would represent the type of soils present in aquifer layers at the riverbank area. Laboratory or in-situ methods can also be conducted to determine the value of hydraulic conductivity. [9] has demonstrated a vibration test for riverbank soil at laboratory using falling head test. The result showed a significant change of K values due to the vibration imposed on the soil specimen. Therefore, this study is intended to further investigate the effect of vibration to the actual soil at riverbank with the following objectives: 1) to assess the hydraulic conductivity (K) pattern at riverbank 2) to improve the hydraulic conductivity through vibration at the riverbank.

2. Methodology

The study area is located at Jenderam Hilir, Dengkil in the southwest state of Selangor within the Langat Basin. It is approximately 4 km to the south of raw water intake of SYABAS water treatment plant. It is located at latitude 2°53'28.56'' N to 2°53'40'' N and longitude 101°41'04.65"E to 101°44'15.32"E. Moreover, Langat River basin is very important for supplying sources of water supply. The land use of Langat River basin consists of mainly agriculture, forest, urban areas, and water bodies [10] and there are two types of forest in Langat River basin area which are peat swamp and mangrove.

The location of study area is connected by three major rivers which are the main Langat River, Semenyih River and Jenderam Hilir River. There are two reservoirs build in study area which is Sungai Langat Dam and Sungai Semenyih Dam. The study area was formerly mining areas which were occupied by a member of lakes. The location of study area consists of alluvial deposits clay, sand and gravel which form shallow aquifer [11]. The unsaturated zone sits on the aquifer consists of clay and the thickness of this clay is approximately 3 m. The aquifer is mostly fine to coarse grained sand with mixture of gravel. Based on the soil investigation result, gravelly sand layer is overlain by a layer of clay, meanwhile other areas are overlain by a layer with low permeability of fine sand which make the aquifer classified as confined or semi-confined aquifer which closely depends on the locations [12]. Furthermore, the estimation depth of bedrock was 20 m.

The pumping wells in study area were initially constructed by National Hydraulic Research Institute of Malaysia (NAHRIM) and its main purpose was to determine the hydraulic permeability of the soil and can be used for another potential research related to riverbank filtration. However, for this study, only two pumping wells were selected for study namely MW01 and MW02. These two pumping wells were selected due to their suitable location which is nearer to the river. The positioning of the wells is shown in Figure 1.
2.1. Slug test procedure

Slug test is conducted to determine the hydraulic conductivity of groundwater zone. It involves the abrupt removal, addition or displacement of a known volume of water and the subsequent monitoring of changes in water level as equilibrium conditions return. Hydraulic properties determined by slug test are representative only of the material in the immediate vicinity of the well. Important information can be obtained about the vertical and horizontal variations of hydraulic properties for the site by performing a series of slug test at discrete vertical intervals and tests in closely spaced wells [13]. It should be noted that the test might be affected by properties of the well filter pack due to localized nature of hydraulic response.

The method of falling head slug test was chosen because it is very cost-efficient and the fastest way to determine the hydraulic conductivity of the soil. It can also be performed by one or two person and multiple tests can be completed in a short period of time. As the test must be conducted in-situ of study area, it is much more accurate and reliable compared to the test that is carried out in the laboratory since the sample is undisturbed due to transferring of sample. There are a few factors that must be considered during conducting falling head slug test which are the diameter of observation well, testing depth, date and time of test being carried out, the weather and water used. The instruments that are essential for this purpose are the water level meter and electronic data logger to record the rise and fall of the water level in the well accurately.

2.2. Determination of hydraulic conductivity (K)

Hvorslev [14] pioneered the development of in-situ field tests, particularly the slug test. The need existed to estimate in-situ hydraulic conductivity for both confined and unconfined aquifers under a variety of well geometric and aquifer condition. The method has been described by Fetter [15] and involves determining the ratio “H/Ho”, where “Ho” is the distance the water level declines upon removal of a slug of water and. For “H” is the height of the water level below the static water level at some time. Then, the ration is plotted versus time on semi logarithmic graph paper. A straight line should be obtained (Figure 2). The determination of hydraulic conductivity of the soil can be calculated using falling head slug test formula which as shown in Equation 1.
where;

\[ K = \frac{A}{FT} \]  

(1)

- \( K \) = Hydraulic conductivity (m/s)
- \( A \) = Cross-sectional area of the well casing (m\(^2\))
- \( T \) = Basic time factor (BS5930:1999, Fig 8) (s)
- \( F \) = The intake factor (BS5930:1999, Fig. 6, case (d))

**Figure 2.** Determination of basic time factor, \( T \) (BS5930:1999, Fig 8)

**Figure 3.** Intake factor, \( F \) (BS5930:1999, Fig. 6 (d))
2.3. Soil vibration at the riverbank

In order to assess the effect of vibration to the soil hydraulic conductivity, a hole of 3 m deep was drilled and served as a vibration hole. The depth was set according to the length of vibrator hose available for this study and the drilled hole was located 3 m away from the river (Figure 4). A concrete vibrator rod was used as the vibration tool and put inside the designated hole. For this study, the riverbank was vibrated with two durations, which were 45 and 60 minutes.

![Figure 4. The concept of vibration application at the riverbank](image)

3. Result and Discussion

The slug tests were carried out at two pumping wells, MW01 and MW02 for two days. The permeability of the soil was determined by conducting slug test before and after the application of vibration in order to record the differences. The vibration was applied inside the vibration hole for two different periods which is 45 and 60 minutes. The hydraulic conductivity ($K$) before vibration for well MW01 and MW02 are then calculated, and the result is shown in Table 1.

| Well   | Vibration Duration (min) | Basic Time Factor, $T$ (s) | Cross section area of casing, $A$ (m$^2$) | Intake Factor, $F$ (m) | Hydraulic Conductivity, $K$ (m/s) |
|--------|--------------------------|----------------------------|------------------------------------------|------------------------|----------------------------------|
| MW01   |                          | 28                         | 0.00196                                  | 9.066                  | 7.72 x 10$^{-6}$                 |
| MW02   |                          | 39                         |                                          |                        | 5.54 x 10$^{-6}$                 |
| MW01   | 45                       | 24                         |                                          |                        | 9.01 x 10$^{-6}$                 |
| MW02   | 45                       | 28                         | 0.00196                                  | 9.066                  | 7.72 x 10$^{-6}$                 |
| MW01   |                          | 37                         |                                          |                        | 5.84 x 10$^{-6}$                 |
| MW02   |                          | 20                         |                                          |                        | 1.08 x 10$^{-5}$                 |
| MW01   | 60                       | 24                         |                                          | 9.01 x 10$^{-5}$       |                                  |
| MW02   | 60                       | 24                         |                                          | 1.20 x 10$^{-5}$       |                                  |

Based on the calculated $K$ values, the percentage of changes for $K$ due to the vibration imposed is quantified and shown in Table 2.
Table 2. Percentage improvement of hydraulic conductivity (K) after vibration

| Wells | Vibration | K before vibration | K after vibration | % of K changes |
|-------|-----------|--------------------|------------------|----------------|
| MW01  | 45 minutes| 7.72 x 10^-6       | 9.01 x 10^-6     | 16.7           |
| MW02  | 5.54 x 10^-6 | 7.72 x 10^-6     | 39.3            |
| MW01  | 60 minutes| 5.84 x 10^-6       | 9.01 x 10^-6     | 54.3           |
| MW02  | 1.08 x 10^-5 | 1.20 x 10^-5     | 11.1            |

During testing on day one for scheduled 45 minutes vibration, both of wells show increasing values in hydraulic conductivity of the soil. The percentage of increase is 16.7% and 39.3% for MW01 and MW02 respectively. The factors that might be involved in increasing hydraulic permeability could be the distance between the monitoring wells and vibrating hole. This is because closer the distance of monitoring well to the vibrating hole will affect the soil structures. Soil particles start to loosen up after applying vibration and allow the water to flow through the well. On second day testing with 60 minutes of vibration, both of wells also show significant increase in K values. The percentage of increase is 54.3% and 11.1% for MW01 and MW02 respectively. The probable factors that might be involved in these increased values could be the longer duration of vibration during conducting test. It is believed that the longer duration of vibration applied in the vibrating hole will make soil structure to face physical changes. The soil particles at the riverbank and along the flow path towards the well screen started to loosen and increase the pore spaces. Therefore, it allows water to flow through the well faster.

It is notable that the percentage increase for MW02 declined from 39.3% to 11.1% with 60 minutes of vibration. The distance of MW02 is slightly greater than MW01 to the vibration hole which could be a possible cause for this decline. Despite this, the possibility of having vibration applied to improve the K values remain as major focus. It has showed that vibration is still able to improve the flow in between the soil pores at the riverbank, and perhaps with more data and assessment with longer and multiple durations of vibration might provide clearer evidence on the effect of the vibration to the hydraulic conductivity improvement.

4. Conclusion

Based on the results obtained during two days of observation, the values of hydraulic conductivity of soil at both pumping well area had increased significantly. For the first trial, the test was conducted with 30 minutes of vibration and the values of hydraulic conductivity of well MW01 and well MW02 increases with 16.7% and 39.3% respectively. The factor that can be related to this result is the duration of vibration applied during conducting the test. It is expected that with a longer duration of vibration, the higher the rate of hydraulic conductivity of the soil. Thus, on the second trial, 60 minutes of vibration was applied at the riverbank and the value of percentage increased for MW01 and MW02 which were 54.3% and 11.1% respectively. The contributing factors that can be related to this result were due to the distance between pumping wells and the vibrating hole. MW01 has higher values in hydraulic conductivity because it is located just 1.5 m from the vibrating hole compared to MW02 which has distance of about 9.35 m further from the vibrating hole. Even though the result showed successful and significant increases in hydraulic conductivity of soil, it still needs more observation and more data for conclusive assessment. As a conclusion, this study has proven that the vibration method can be considered as an effective way in improving the hydraulic conductivity at any groundwater pumping site which also able to improve the groundwater abstraction.
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