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STUDY ON WATER QUALITY OF UNCONFINED AND CONFINED AQUIFER IN SELANGOR: AERATION METHOD

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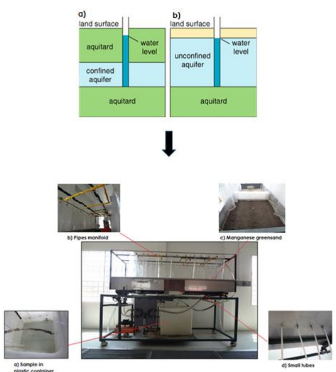
Graphical abstract



Aeration process to treat a) confined and b) unconfined groundwater

Abstract

The quality of groundwater depends on quality of water recharging the aquifer and the hydrologic and biogeochemical processes in it. In order to treat specific water properties and heavy metals present in groundwater, aeration and filtration process is applied. The objectives of this study are i) to investigate the groundwater properties collected from unconfined and confined aquifer, and ii) to analyze the groundwater properties varied by aeration period in a small tanks. The removal efficiency for turbidity, iron and manganese fall in the range of 25% to 30%, 9% to 66% and 50% to 90% for all samples, respectively. The dissolved oxygen content did influenced the average value of studied parameters, especially for pH value of confined samples, within 3 hours aeration, the value increase from 4.88 to 7.28, which is fulfil the requirement of Malaysian standard. It can be concluded that for all parameters observed, there were changes in values either increased or decreased throughout the aeration and filtration process for both studied aquifers.

Keywords: Aquifer, confined, heavy metals, unconfined, water quality

Abstrak

Kualiti air bawah tanah bergantung kepada imbuhan semula air dalam akuifer dan proses hidrologi dan biogeokimia di dalamnya. Bagi tujuan merawat ciri-ciri air yang tertentu dan logam berat yang hadir dalam air bawah tanah, proses pengudaraan dan penapisan digunakan. Objektif kajian adalah i) untuk menyiasat sifat air bawah tanah yang diambil dari akuifer tak terkurung dan terkurung, dan ii) untuk menganalisa sifat air bawah tanah dibezakan dengan masa pengudaraan di dalam tangki kecil. Kecekapan penyingkiran bagi kekeruhan, besi dan mangan berada dalam julat 25% hingga 30%, 9% hingga 66% dan 50% hingga 90% bagi semua sampel, masing-masing. Kandungan oksigen terlarut mempengaruhi nilai purata parameter yang dikaji terutama sekali pada nilai pH sampel terkurung, sepanjang 3 jam pengudaraan, nilai meningkat dari 4.88 ke 7.28, yang mana memenuhi keperluan standard Malaysia. Ini boleh disimpulkan bahawa bagi kesemua parameter yang dikaji, terdapat perubahan dalam nilai samada meningkat atau menurun sepanjang proses pengudaraan dan penapisan bagi kedua-dua akuifer yang dikaji.

Kata kunci: Akuifer, kualiti air, logam berat, terkurung, tak terkurung

1.0 INTRODUCTION

In 1998, Selangor had experienced a long period of drought causing severe water shortage due to the lower water level in Langat and Semenyih dam. For about three months of water rationing was imposed for residents in Klang Valley. This water crisis has triggered the government to find other water source instead of fully dependable on surface water. Moreover, water consumption of Malaysia in 2012 – 2013 shows an increased at 61.5% and 38.5% for domestic and non-domestic used, respectively [1].

In Selangor state, the consumption of water in 2012 -2013, also shows a slight increase which is 58% and 42% for domestic and non-domestic used, respectively. Malaysian government has stated its intention to further expand water supply and due to that the National Economic Action Council (Malaysia) had identified groundwater as one source that has great potential to be developed. The Geological Survey in Peninsular Malaysia has been involved in groundwater investigations since its inception in 1903 (2). By referring to the hydrogeological map of Peninsular Malaysia [3]; Kuala Lumpur Federal Territory, Selangor and Kelantan are states with most active wells. All these wells are located in high and very high aquifer potential.

However, according to National Hydraulic Research Institute of Malaysia (NAHRIM) [4], rapid development had exposed groundwater to contamination as being discussed in report produced by geohydrology research center which assessed the water quality based on pumping effect and land use activity. Muhkhtar et al., [5] indicated that high concentration of contaminants exists in the downstream area coinciding with local groundwater flow. Iron and manganese are naturally occurring elements which are commonly found in groundwater and their concentration varies with the depth and location of the well also the geology of an area. The metals present in deeper wells where the groundwater may have little or no oxygen, and in areas where groundwater flows through soils rich in organic matter.

The concentration of iron and manganese in well water can fluctuate seasonally. Moreover, the quality of groundwater depends on the quality of water recharging the aquifer and the hydrologic and biogeochemical processes that affect it along flow paths from recharge to discharge areas (6). A variety of chemical, physical and biological processes can alter the chemistry of water as it is moves along flow paths from recharge areas to points deeper in the aquifer. Chemical processes include mineral dissolution and precipitation and ion exchange, which are referred as water/rock interactions (7).

In general, the groundwater was treated with the process as aeration and filtration for removing iron and manganese either for domestic consumption of irrigation purposes (8-12]. The objectives of this paper are i) to investigate the groundwater properties by referring to the type of aquifer, and ii) to analyze the groundwater properties during aeration process in a small tanks.

2.0 METHODOLOGY

2.1 Sampling Location

The location of groundwater sampling were chosen based on type of aquifer located at industrial sites in Selangor (Figure 1). The hydrogeological information and data were referred to sample collected from tube well at specific locations. For the time being these wells are active and used for industrial and domestic purposes.

Wells classified into their usages (agriculture, domestic, industrial, monitoring and natural mineral water. Wells also are categorized into low (orange region), medium (yellow region), high (green region) and very high (blue region) aquifer potential and whether it is an active, inactive or abandoned/not found/unknown well. Kuala Lumpur Federal Territory, Selangor and Kelantan are states with most active wells due to their locations which are located in high and very high aquifer potential.

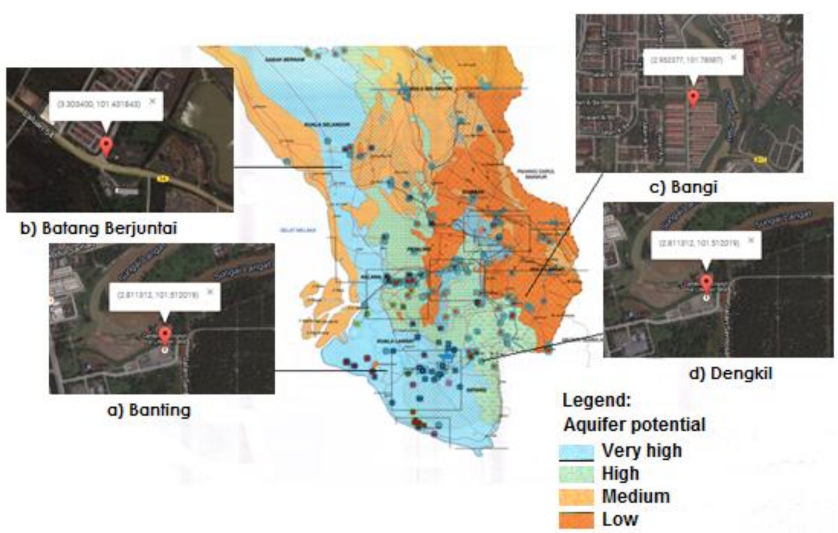


Figure 1 Hydrogeological map of Selangor state and the location of four sampling points [3]

Groundwater samples were collected at four different sites; two sites for each type of aquifer (Table 1) categorized by unconfined aquifer (namely sample A and B) and confined aquifer (namely Sample C and D). Table 1 also tabulated the information of the wells such as location, coordinate and type of aquifer. Sample A and B are from unconfined aquifer (alluvium, peat/ soil) and sample C and D are from confined aquifer (hard rock).

Table 1 Location of groundwater sampling and type of aquifer

Sample	Location	Coordinate	Type of Aquifer
A	Dengkil	2° 52' 0" N 101° 40' 0" E	Unconfined (peat/soil)
B	Banting	2° 49' 0" N 101° 30' 0" E	Unconfined (alluvium/soil)
C	Bangi	2° 54' 0" N 101° 47' 0" E	Confined (Hard rock)
D	Batang Berjuntai	3° 23' 0" N 101° 25' 0" E	Confined (Hard rock)

Table 2 described the details of each sample collected for this study in terms of total depth, type of aquifer, lithology, usage, quality and potability, aquifer potential and the yield amount for each tube well. From hydrogeological data tabulated in the table; sample A (Dengkil area) can be categorized as a high aquifer potential with sediment and metamorphic rocks which is phyllite, while Sample B (Banting area) is very high aquifer potential with unconsolidated deposits (clay and silt). Sample C (Bangi area) was classified as a high aquifer potential with sediment and metamorphic rocks of phyllite. Sample D (Batang Berjuntai area) is a medium aquifer potential with sediment and metamorphic rocks of schist and sandstone.

It can be summarized that the total depth for confined aquifers is normal depth compared to unconfined aquifers and their geological formation form from hard rock. All samples were categorized as fresh and generally potable water and each tube well with more than 10 to 20 m^3/hr.

Table 2 Information and data for samples collected at four selected industrial sites referred from borehole and Hydrogeological Map of Selangor [3]

Sample/ Location	Total Depth (m)	Type of Aquifer	Geological Formation (borehole)	Lithology	Well Usage	*Quality and Potability of Water	Aquifer Potential	Tube Well with Yield (m^3/hr)
A/ Dengkil	60.00	Unconfined	Peat, clay, silt and gravelly coarse sand	Unconsolidated deposits: peat, humic clay and silt Sediment and metamorphic rocks: Phyllite, schist and slate	Industrial Monitoring Domestic	Fresh, generally potable (TDS< 1,500 mg/L) Moderately saline, suitable for livestock (TDS5,000 – 10,000 mg/L) Slight saline, marginally potable (TDS 1,500 – 5,000 mg/L)	Very high	>10.0 to ≤20.0
B/ Banting	36.58	Unconfined	Alluvium, fine and coarse sand	Unconsolidated deposits: clay and silt	Monitoring	Fresh, generally potable (TDS< 1,500 mg/L) Moderately saline, suitable for livestock (TDS5,000 – 10,000 mg/L) Slight saline, marginally potable (TDS 1,500 – 5,000 mg/L)	Very high	>10.0 to ≤20.0
C/ Bangi	110.00	Confined (Hard rock)	Hard rock – weathered and slightly weathered	Sediment and metamorphic rocks: Phyllite	Domestic Industrial	Fresh, generally potable (TDS< 1,500 mg/L)	High	>10.0 to ≤20.0
D/ Batang Berjuntai	122.00	Confined (Hard rock)	Hard sandstone – slightly and highly fracture	Sediment and metamorphic rocks: Schist	Industrial Monitoring	Fresh, generally potable (TDS< 1,500 mg/L)	Medium to Low	>10.0 to ≤20.0

*based on Total Dissolved Solid (TDS) only

2.2 Methods

In this study, the groundwater samples were collected at four different sites categorized as unconfined and confined aquifer. Figure 2 shows the groundwater sampling process where an existence of tube well with tap (Figure 2a) at site was used to collect the groundwater sample. A container of high-density polyethylene plastic (20 liters) was used to keep the sample and a pipe hose was used to connect the tap from the tube well (Figure 2a) to the containers. Figure 2(b) and (c) show the examples of groundwater samples collected from two types of aquifer; unconfined and confined, respectively. It can be seen that the confined groundwater sample is clearer compared to unconfined sample.

Figure 2 Groundwater sampling (a) example of tube well, (b) example of groundwater sample collected from confined aquifer and (c) example of groundwater sample collected from unconfined aquifer

About 100 liters volume of groundwater sample were collected for each site to accommodate the equipment in order to run the treatment process which is aeration (water-into-air) and followed by manganese greensand filtration. Manganese greensand (formulated from a glauconite greensand) is capable of reducing iron, manganese and hydrogen sulfide from water through oxidation and filtration.

Figure 3 shows a small scale tank equipment used in this study to run the treatment process. It consist of plastic tank, pipes manifold, filtration basin and several small tubes at the bottom.

Figure 3 Equipment set-up for groundwater treatment (i.e. aeration followed by filtration) processes (a) plastic tank contained water sample, b) pipe manifold with spray nozzles, (c) manganese greensand basin and (d) small tubes at the bottom of basin

Groundwater samples were treated by aeration process (water-into-air method) and filtration process with a final polish using manganese greensand. The properties of groundwater such as pH, dissolved oxygen, turbidity and metal concentration (iron and manganese) will be assessed before, during and after the process (3, 5 and 7 hours). Furthermore, a comparison between two types of aquifer; unconfined and confined was carried out.

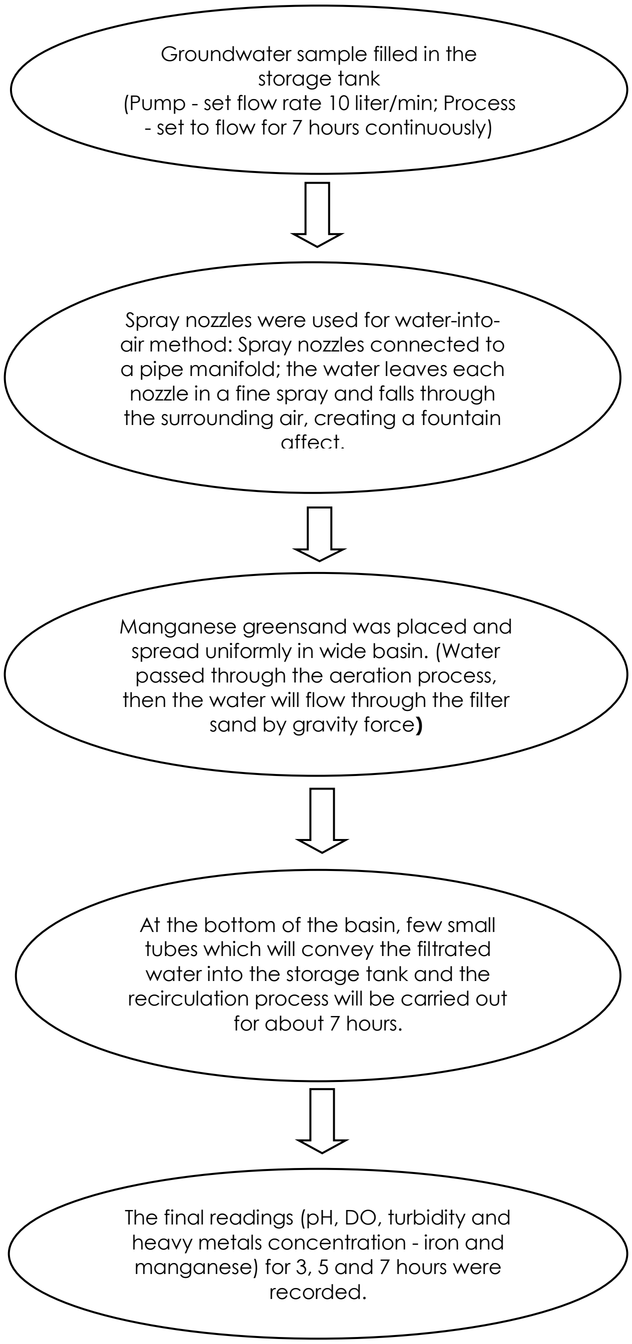


Figure 4 Flow chart of the treatment process carried out in laboratory

The flow chart of the treatment process is shown in Figure 4. Sample was filled in the storage tank and water pump was used to make sure the flow rate was set at 10 liter/min. The process was set to flow for 7 hours continuously. The amount of water used (100 L) is adequate for water recycling condition (zero discharge).

3.0 RESULTS AND DISCUSSION

Table 3 and 4 show the summary of results for groundwater samples collected from unconfined and confined aquifer, respectively.

Each of these results will be compared to standard used in Malaysia for drinking water purposes, National Drinking Water Quality standard (NQWS) by Ministry of Health (MOH). According to the initial results tabulated in the tables; it can be stated that the average initial pH reading is neutral for unconfined aquifer however the average initial pH reading for confined aquifer is acidic maybe due to its lithology properties. According to Zhao et al. [13], there a several factors that contributes to lower pH of confined aquifer such as the acidity of rainwater, from dissociation of H_2CO_3, release of the absorbed H_3O^+ in clay layers and lack of alkaline substances in the groundwater systems produce an accumulation of groundwater acidity. Moreover, referring to Carter [14], it is natural that groundwater samples (not affected by human activities) having lower pH since it is controlled primarily by the chemical properties of rainwater in combination with minerals and biological activity in the soil and aquifers.

The final results of dissolved oxygen (DO) values for both aquifers are increased throughout the treatment process. The rate of dissolved oxygen content observed throughout the aeration process for 3, 5 and 7 hour duration of all samples are constant such as for sample A, the value is around 4.8, sample B is 6.2 and sample C and D are 5.9. The final turbidity value of unconfined aquifer was higher compared to the confined aquifer. Iron and manganese final concentrations of confined aquifer are higher compare to unconfined aquifer and above the standard for both aquifers except for iron concentration from Sample D.

Table 3 Results for groundwater samples collected from unconfined aquifer

Parameters	Standards *NDWQ [15]	Initial [8]		Final						Removal Efficiency (%)	
				3 hours		5 hours		7 hours [16]			
		A	B	A	B	A	B	A	B	A	B
pH	6.5 – 9.0	7.06	7.04	8.08	8.31	8.19	8.37	8.34	8.38	**-18.1**	**-19.0**
Dissolved Oxygen, DO (mg/L)	-	5.34	6.14	5.79	7.19	5.80	7.23	5.92	7.30	**-10.9**	**-18.9**
Turbidity (NTU)	<5	39.2	27.4	32.0	25.2	31.3	19.8	29.3	19.1	**25.3**	**30.3**
Iron (mg/L)	<0.3	0.98	0.79	0.92	0.60	0.71	0.52	0.89	0.46	**9.2**	**41.8**
Manganese (mg/L)	<0.1	0.17	0.10	0.05	0.02	0.03	0.02	0.08	0.02	**52.9**	**80.0**

Sample A =Dengkil; Sample B =Banting
*NDWQS - National Drinking Water Quality Standard by Ministry of Health - MOH, Malaysia [15]

Table 4 Results for groundwater samples collected from confined aquifer

Parameters	Standards *NDWQ [15]	Initial [8]		Final						Removal Efficiency (%)	
				3 hours		5 hours		7 hours [16]			
		C	D	C	D	C	D	C	D	C	D
pH	6.5 – 9.0	4.88	5.55	6.96	7.28	7.24	7.47	7.46	7.63	**-52.9**	**-37.5**
Dissolved Oxygen, DO (mg/L)	-	5.91	6.40	6.81	6.76	6.89	6.91	7.10	6.98	**-20.1**	**-9.1**
Turbidity (NTU)	<5	5.73	9.17	4.95	8.02	4.67	6.60	4.25	6.32	**25.8**	**31.1**
Iron (mg/L)	<0.3	7.56	N. D	5.91	N. D	5.22	N. D	2.53	N. D	**66.5**	**N. D.**
Manganese (mg/L)	<0.1	0.55	0.17	0.43	0.14	0.13	0.09	0.04	0.06	**92.7**	**64.7**

N. D. = not detected; Sample C = Bangi; Sample D = Batang Berjuntai
*NDWQS - National Drinking Water Quality Standard by Ministry of Health - MOH, Malaysia [15]

From both tables, it can be summarised that the removal efficiency for turbidity, iron and manganese fall in the range of 25% to 30%, 9% to 66% and 50% to 90% for all samples, respectively. In detail assessment, the average final pH values for all samples after 3, 5 and 7 hours treatment process is in the range of 7.04 to 8.38 and 4.88 to 7.63 for unconfined aquifer (sample A, B) and confined aquifer (sample C, D) water samples, respectively. It can be summarised that the pH values after treated is within the range of standard requirements for Malaysian.

In general, the water-into-air aeration methods have increased dissolved oxygen concentration and caused a decrease pattern in parameters studied in this paper which are turbidity, manganese and iron of groundwater samples regardless of sampling location. Specifically on turbidity and manganese content, the first three hours aeration process give a huge impact to the parameters concentration. With the constant dissolved oxygen content, the trend for manganese concentration is drastically reduce for the first three hours treatment process.

Dissolved oxygen and turbidity properties are used to describe the water chemistry in the aquifer. According to Rose and Long [16], the DO concentration has a significant effect upon groundwater quality by regulating the valence state of trace metals and by constraining the bacterial metabolism of dissolved organic species. The final values of turbidity for all studied samples showed a decreased pattern throughout the treatment process. However, the final values except for Sample C still did not fulfil the standard values required by Malaysian government which is less than 5 NTU for drinking purposes. The initial turbidity for unconfined and confined aquifers were too high to be treated using this treatment scheme. According to Kenworthy [17], the analysis of several flow in a karst conduit reveals that peaks in turbidity and suspended solids concentration display a complex relationship to variations in flow hydraulics. Based on study conducted by Nebbache et al. [18], for a karstic catchment, the mechanisms which explain changes in turbidity and nitrate, results from a strong continuity between surface and underground waters.

For iron and manganese concentration, it can be concluded that there were reduction pattern for all samples except for samples D where iron was not detected. By referring to the standard pH and manganese final value, show that the results was in an acceptable range for drinking purposes for each confined and unconfined aquifers.

Samples collected from unconfined (sample A, B) and confined aquifers (sample C) show high concentration of iron and even 7 hours of treatment was inadequate to reduce it to acceptable levels (Fig. 5a). However, for manganese, the reduction pattern was obvious especially for sample C which is from confined aquifer (Figure 5b).

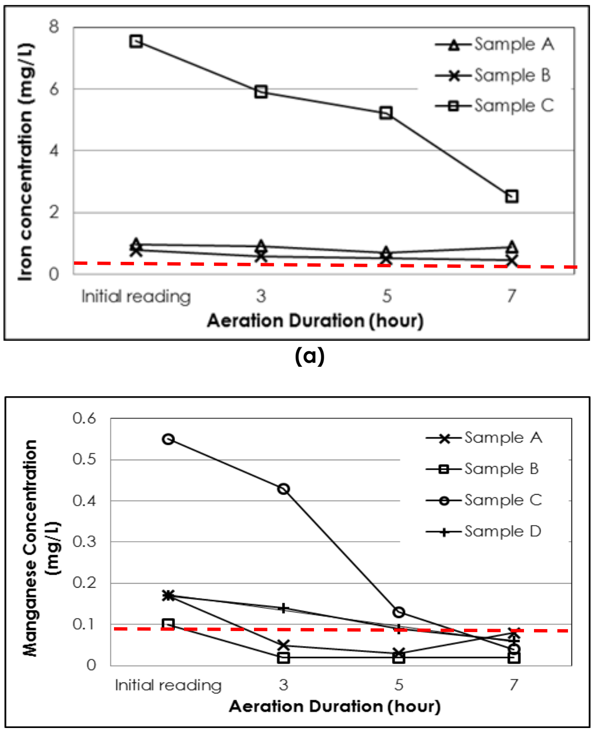


Figure 5 (a) The reduction pattern of (a) iron and (b) manganese throughout 7 hours treatment

Figure 6 show a relationship between dissolved oxygen and manganese during the treatment process for all samples.

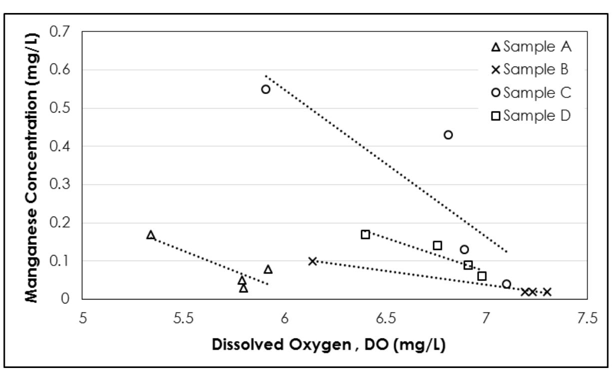


Figure 6 The relationship between manganese concentration and dissolved oxygen for 7 hours treament

From the figure, manganese concentration reduce when dissolved oxygen increase. According to Kohl and Medlar [19], the direction of manganese cycling depends upon the dissolved oxygen in water. When adequate DO is available, aerobic condition predominate and MNO_2 is formed and precipitates from the water. Throughout the aeration period, oxygenated water will prevent the iron and manganese from dissolving and the water produce will have low concentration of the metals. The oxygen supplied during the treatment will precipitate iron and manganese from the water.

The iron concentration for each aquifer not showing an impressive results for the aeration and filtration method. Table 5 tabulated the trend line equations and regression values for samples (A-C) to study more on the reduction pattern of iron concentration.

It shows that satisfying values will be achieved for sample A and B if the treatment is prolong for another 5 hours based on the regression values above 0.5.

Table 5 The trend line equation and regression values forecast of iron (confined and unconfined aquifer)

Samples	Trend line Equation	Regression values, R^2
A	$y = -1.578x + 9.25$	0.9462
B	$y = -0.107x + 0.86$	0.9252
C	$y = -0.048x + 0.995$	0.2844

The linear trend line method can be recommended for future prediction of iron in sample A and B. However, R^2 value for sample C is low and it is not fitted into a linear equation.

4.0 CONCLUSION

The assessment and treatment of groundwater collected from confined and unconfined aquifer was carried out and discussed in this paper.

Final pH and dissolved oxygen values for all samples (unconfined and confined aquifers) were fall in the range of the acceptable values by Ministry of Health, Malaysia (12) and Department of Environment, Malaysia (13) regarding to drinking water quality standard. National Drinking Water Quality Standard.

The application method of water-into-air with additional usage of manganese greensand as a filter media showed removal of manganese concentration below 0.1 mg/L. The removal percentage for manganese has showed a higher percentage among others with 80% for sample B (unconfined aquifer) and 90% for sample C (confined aquifer). However, for iron concentration removal of sample collected from unconfined aquifer site is not very effective not reach 50% removal) but there was a reduction in value.

In conclusion, the water-into-air aeration method with additional filtration can effectively increase and reduce specific parameters values to the drinking water quality standard required by Malaysian Government except for iron from samples collected from confined aquifer.

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