Assessment of Groundwater Potential as Alternative Water Resource for Kapar Power Plants

Nur Iffika Ruslan*, *Masitah* Alias

Built Environment and Climate Change Unit, TNB Research Sdn Bhd, No. 1, Lorong Ayer Itam, Kawasan Institusi Penyelidikan, 43000 Kajang, Selangor, Malaysia

Abstract. The current surface water shortage due to drought is prompting industries in Peninsular Malaysia to explore alternative water resources (AWR). Tenaga Nasional Berhad (TNB)'s reliance on town water has increased the risk of interruptions in supply, exposing the plant to shutdowns and reduced generation capacity. Consequently, TNB requires alternative water sources to mitigate these risks. This study aims to assess the groundwater potential at the Kapar Power Plant in terms of volume and quality as an alternative resource. Hydrogeological and geophysical surveys were conducted to locate prospective groundwater and determine its characteristics. Specifically, 2-D Electrical Resistivity Imaging (ERI) and Induced Polarization (IP) surveys were carried out using the ABEM Terrameter SAS 4000 and the ES10-64 electrode selector. A total of five survey lines were established, revealing four potential groundwater locations. However, two locations were selected for further evaluation, with a total yield of 15.5 m^3/hr. This study provides valuable insights into utilizing groundwater as a sustainable alternative water source for TNB, helping to ensure operational stability and reliability for the power plant.

1 Introduction

By 2030, the world is projected to face a global water deficit under the business-as-usual scenario. A study in 2007 by the National Hydraulic Research Institute (NAHRIM) concluded that Peninsular Malaysia will be potentially exposed to the vulnerability of global warming effects due to the decrease of annual rain in several states as the projected dry year in 2020, 2029, 2034 and 2044 [1]. Selangor is considered a water-stressed region, and it is also being affected by global warming due to the rise in water demand and the scarcity of suitable fresh water supplies for distribution and treatment. Due to these scenarios, the state water authority may decide to adopt scheduled water rationing or take other drastic measures [2].

Kapar Energy Ventures (Kapar Power Plant), owned by TNB, is Malaysia's second-largest thermal power plant with a generating capacity of 2,200 MegaWatt. It is located in the coastal area, facing the Strait of Malacca, approximately 8 km from Kapar town in Klang, Selangor. Geologically, the area is covered by thick alluvium of Quaternary age, underlain by metamorphic basement of Lower Paleozoic age. The vast mudflat area covering the

* Corresponding author: iffika.ruslan@tnb.com.my

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shoreline was vegetated with mangrove forests. The power station is surrounded by coconut and palm oil vegetation, manufacturing industries, residential areas and shipping port [3].

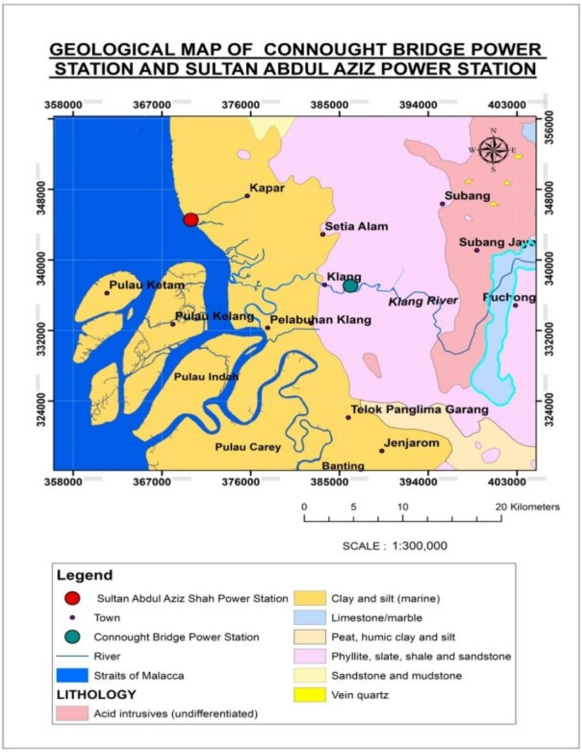

Fig. 1. Geological Map of Kapar Power Plant

Unscheduled water rationing due to the global warming effect and river pollution may seriously impact plant operations. Hence, the identification of potential groundwater within the coastal area as AWR is crucial for the application in Kapar Power Plant to reduce the dependency on the town water during water shortage. The objective of this study is to determine the groundwater potential within Kapar Power Plant in terms of its volume and quality to be used as an alternative water resource within the power plant.

In coastal areas, this priceless resource is severely impacted by seawater intrusion [4]. Seawater intrusion, which is defined as the landward incursion of seawater, will deteriorate the quality of the water in inland freshwater groundwater systems [5]. Any decrease in fresh groundwater flowing into the ocean can result in seawater intrusion. This affects irrigation systems, private boreholes, and the availability of drinkable water. [6].

The issues of groundwater within the coastal regions have also been caused by climate change, sea level rise (SLR), over-pumping of groundwater and changes in land cover, which results in groundwater quality degradation and subsequent reduction in groundwater quantity [4]. It has been demonstrated that coastal aquifers are more vulnerable to groundwater extraction under a variety of hydrogeological conditions than sea-level rise predicted by global climate models [7]. Saltwater intrusion and improper human waste disposal management are the main causes of the deterioration in groundwater quality in coastal aquifers. These factors should be closely monitored as they will limit the availability of potable water for residential and commercial use in the near future [8].

2 Methods

This study implemented two (2) main methods, namely hydrogeological surveys and geophysical surveys to locate the prospective of groundwater and to determine the volume and quality of groundwater in the tube wells, respectively. Hydrogeological surveys were conducted by interpreting rainfall data and analyzing water quality of the existing monitoring wells within Kapar Power Plant. Under this survey, a few activities have been done, such as a literature review on the past report and performing field observation for six (6) settlement points that have been identified within the power plant. Figure 2 and Table 1 show the map and coordinates of rainfall stations within the power plant.

Fig. 2. Map of rainfall stations within Kapar Power Plant.

Table 1. Coordinates of rainfall stations within Kapar Power Plant

No.	Rainfall Station	Coordinates (Latitude, Longitude)
1	2914420	2°58'55.33"N, 101°25'27.84"E
2	3014092	2°59'20.49"N, 101°24'17.64"E
3	3014093	3° 3'19.60"N, 101°25'28.32"E
4	3014091	3° 2'46.58"N, 101°26'34.44"E
5	3014094	3° 1'9.09"N, 101°30'40.04"E
6	3014089	3° 5'35.12"N, 101°26'25.85"E
7	3113087	3° 6'42.54"N, 101°22'26.59"E
8	3114086	3° 7'28.73"N, 101°23'8.77"E
9	3013002	3° 7'59.71"N, 101°21'31.84"E
10	3113059	3°10'35.07"N, 101°20'28.64"E

Geophysical surveys deployed ERI, IP, drilling and hydrogeological pumping tests. Electrical resistivity (ERI) was a geophysical investigation technique based on detecting differences in electrical conductivity or resistivity in the ground. The purpose of the electrical resistivity survey was to detect the presence of potential groundwater zones, either in alluvium or in hard rock aquifer. Induced polarization (IP) survey was a geophysical technique aimed at determining the charge of subsurface material in milliseconds (ms) units. The technique was based on the ability of subsurface material to induce current when it was subjected to direct current from the surface. The ERI and IP surveys were carried out using ABEM Terrameter SAS 4000 and ES10-64 electrode selector. A total of five (5) survey lines were acquired at the proposed sites using a pole-dipole array to obtain the expected minimum depth of 150 meters. The survey lines and their length, which represented SAA1 (500 meters), SAA2 (400 meters), SAA3 (400 meters), SAA4 (400 meters) and SAA5 (200 meters), were arranged with a minimum spacing of 5 meters. The geophysical data were processed using RES2DINV software to produce inverse model (pseudosections), also known as resistivity profile and/or induced polarization profile.

Groundwater abstraction was employed to identify the volume and quality of groundwater tube wells. The important steps in developing tube wells are drilling, pumping tests, and lab analyses. Drilling is an important process to confirm whether the potential location of a tube well by geophysical survey has water. Meanwhile, the hydrogeological pumping test is a practical approach to estimating well performance, well capacity, the zone of influence of the well and aquifer characteristics. Finally, lab analysis is required to assess the groundwater quality, whereby the results are significant in determining the suitability of using this resource as an alternative water supply in the power plant. Figure 3 shows the survey lines plotted on a Google Earth image meanwhile Table 2 shows the details of survey lines used in the study.

Fig. 3. Survey lines on Google Earth Image at Kapar Power Plant

Table 2. Details of survey line carried out at Kapar Power Plant.

Survey Line	Coordinates		Electrode Protocol	Length (m)	Minimum Electrode Spacing (m)	Expected Maximum Depth (m)
SAA1	SAA1 – 0m	3° 7'7.06"N, 101°19'5.00"E	Pole-dipole	500	5	150
	SAA1 – 500m	3° 7'13.81"N, 101°19'19.16"E				
SAA2	SAA2 – 0m	3° 7'28.79"N, 101°19'14.37"E	Pole-dipole	400	5	150
	SAA2 – 400m	3° 7'14.84"N, 101°19'21.62"E				
SAA3	SAA3 - 0m	3° 6'49.02"N, 101°19'19.10"E	Pole-dipole	400	5	150

	SAA3 – 400m	3° 6'54.93"N, 101°19'30.73"E				
SAA4	SAA4 - 0m	3° 6'56.62"N, 101°19'24.53"E	Pole-dipole	400	5	150
	SAA4 – 400m	3° 6'44.90"N, 101°19'30.20"E				
SAA5	SAA5 - 0m	3° 6'47.91"N, 101°19'15.24"E	Pole-dipole	200	5	70
	SAA5 – 200m	3° 6'46.47"N, 101°19'21.59"E				

3 Result and Discussions

3.1 Hydrogeological Survey

3.1.1 Rainfall Stations

Based on the nearest rainfall stations, Ladang Bkt Kerayong Station The (Station 3113059), Ladang Sg. Kapar Station (3113087) and Jalan Sg. Kapar Besar Station (Station 3013002), the area exhibited higher rainfall capacity in the months of October and November and lower rain capacity in early January and February. From 2008 – 2015, the average annual rainfall data recorded at Jalan Sg Kapar Besar Station ranged from 1400 to 2395 mm/year. Meanwhile, the average annual rainfall data at Ladang Bkt Kerayong Station in the years 1962 – 2015 ranged from 1000 to 2818 mm/year. For Ladang Sg Kapar Station, the rainfall data ranged from 900 to 3000 mm/year, except for the year 2011 (4594 mm/year) [10].

3.1.2 Monitoring Wells

Figure 4 shows five (5) existing monitoring wells that were used within the power plant, whereby their water quality has been analysed as shown in Table 3. The existing monitoring wells were used by the power plant to monitor the potential for leaching, which may be attributed to the power plant's operation.

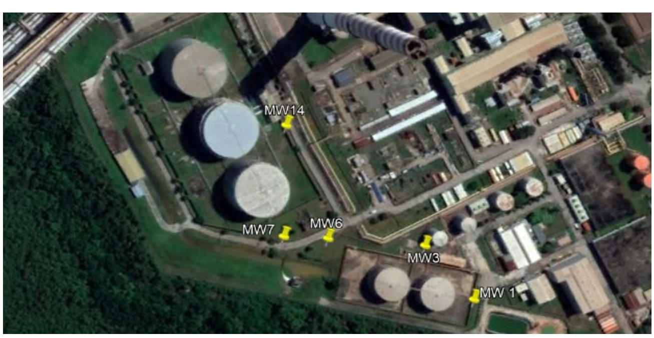

Fig. 4. Location of existing monitoring tube wells within Kapar Power Plant.

Table 3. Water quality analysis for five (5) existing monitoring wells.

Well	Coordinates (Latitude, Longitude)	Water Level (m.b.g.l)	Well Depth (m.b.g.l)	Elevation (m.a.s.l)	TDS g/L	Cond. (ohm m)	pH	Salinity (ppt)
MW1	3° 6'47.29"N, 101°19'21.56"E	0.85	1.71	24	2.109	2.7268	6.52	1.68
MW3	3° 6'48.85"N, 101°19'20.22"E	0.55	1.59	24	2.377	2.4724	6.69	1.91
MW6	3° 6'49.60"N, 101°19'18.38"E	0.62	1.48	21	1.054	5.5557	7.22	0.81
MW7	3° 6'49.13"N, 101°19'16.33"E	0.85	1.44	22	1.148	4.9485	6.95	0.88
MW14	3° 6'53.02"N, 101°19'16.32"E	1.11	1.68	23	1.235	4.636	7.35	0.95

Figure 5 shows nine (9) borehole data with maximum 65 metres penetration that were used for the subsurface geology interpretation. Based on the result, the area has a very thick alluvium (10-40 meters thick), which constitutes greenish from very soft to soft silty clay, with pockets of loose sand and minor occurrence of gravels containing decayed wood and sea shells. This layer was similar to marine clay deposits [11]. The layer was underlain by compacted alluvium (from 35 meters depth) characterized by interbedded dense to very dense silty sand and medium stiff to stiff clay/clayey silt, containing decayed wood and minor occurrence of gravel.

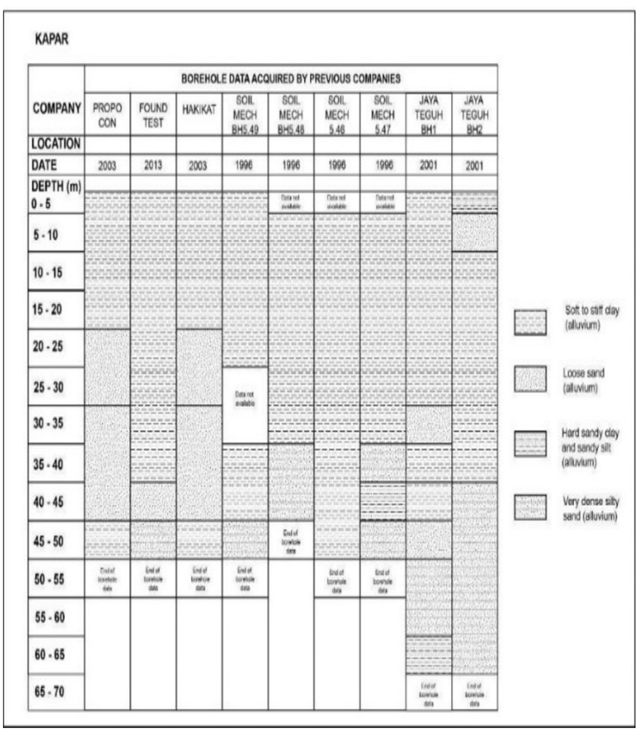

Fig. 5. Borehole data log.

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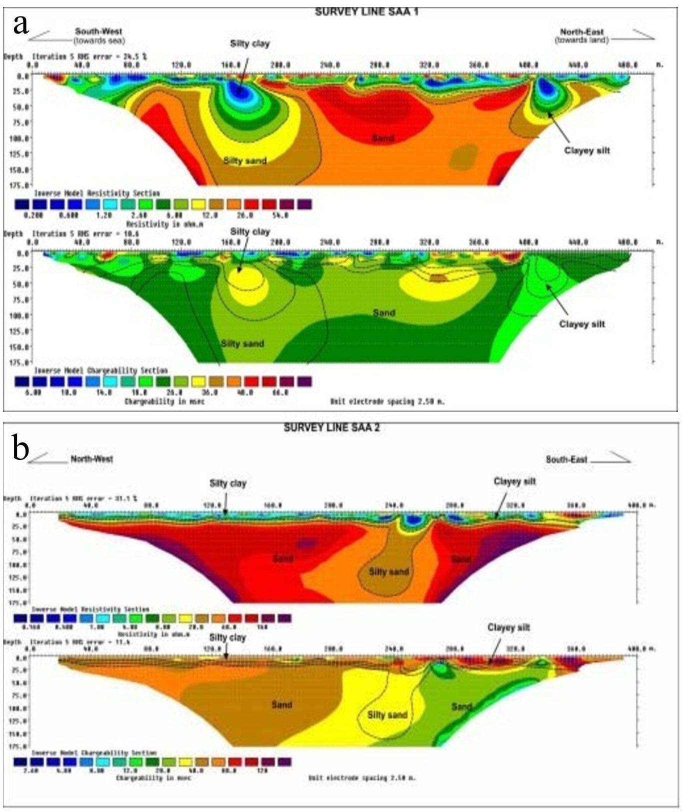
3.1.3 Potential of Ground Settlement

Land subsidence might prevail due to groundwater exploitation and land clearance in peat areas. Based on field observation conducted, the land settlement had already prevailed even before the groundwater abstraction was carried out. Six (6) settlement points have been identified within the power plant, whereby the measurements at these locations show that the structure was shifted 15.5 – 74.5 cm from its original basement, indicating land settlement. The power plant area was affected by land subsidence due to the thick alluvium and occurrences of peaty layer in the surrounding area. This area has been cleared for agricultural activities and residency for decades.

3.2 Geophysical Survey

Figure 6 below shows the results of resistivity and induced polarization profiles for SAA1 – SAA5 survey lines at Kapar Power Plant.



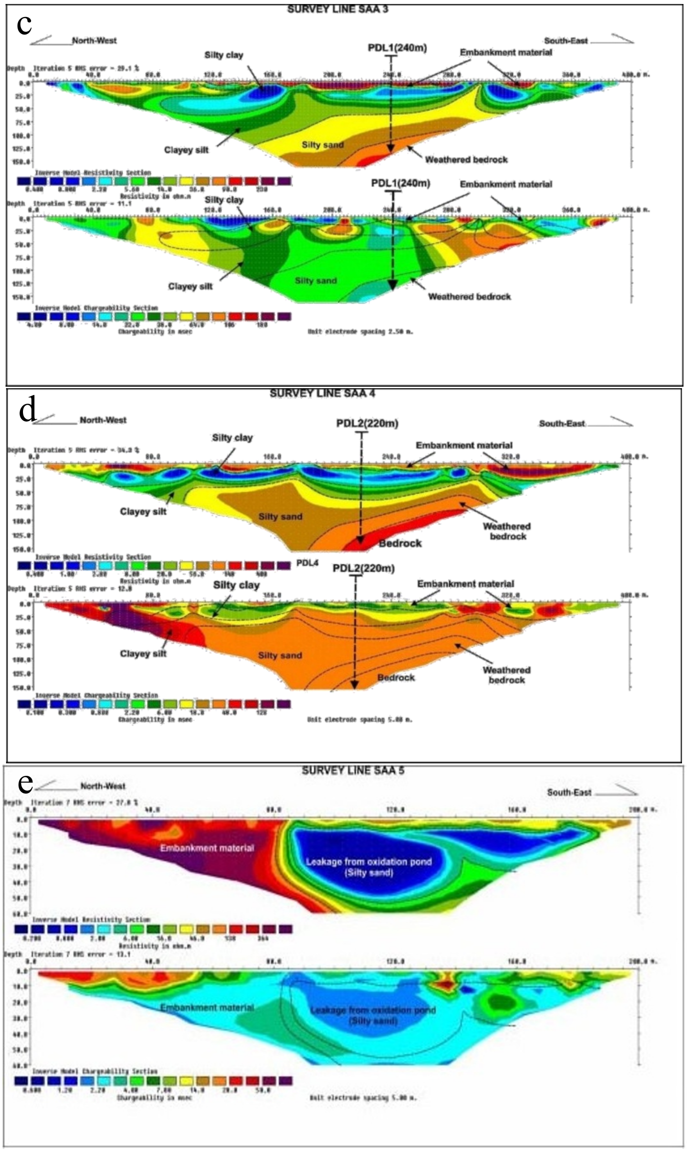


Fig. 6. Resistivity and induced polarization profiles for survey lines at Kapar Power Plant (a) SAA1; (b) SAA2; (c) SAA3; (d) SAA4; (d) SAA5.

Based on the resistivity and induced polarization data assisted with borehole data, the subsurface of Kapar Power Plant could be classified into three (3) major layers, namely soft alluvium, compacted alluvium and weathered bedrocks. Among the survey conducted, only two (2) survey lines (SAA3 and SAA4) indicated groundwater potential, especially in weathered bedrock. Hence, the proposed drilling location was SAA3, followed by SAA4.

Based on the results, SAA3 indicated two types of aquifer zones were interpreted in the station, the shallow and deep aquifers. Shallow aquifer was indicated by low resistivity zone at the top 25 meters of the resistivity profile (0.4-5.6 Ωm) and low chargeability values (4-22 msec). Deep aquifer indicated by the medium to high resistivity zone at the alluvium-weathered bedrock boundary. The soft silty clay and loose sand alluvium were represented by intermediate resistivity values (5.6-25 Ωm), whereas the dense silty sand and medium stiff to stiff silty clay or clayey silt were represented by slightly higher resistivity values (25-63 Ωm). The alluvium was underlain by weathered bedrocks represented by high resistivity values (63-230 Ωm). The deep aquifer or groundwater potential zone (PDL1) was interpreted in weathered bedrocks at 150 m depth. Thus, the proposed drilling location for PDL1 was at a 240 m survey line, with a minimum depth of 150 m for drilling.

SAA4 indicated two types of aquifer zones were interpreted in the station, the shallow and deep aquifers. Shallow aquifer was indicated by low resistivity zone at the top 25 meters of the resistivity profile (0.4-5.6 Ωm) and low chargeability values (0.1-12 msec). These values were interpreted as interstitial water in marine clay and not possibly be tapped. Deep aquifer was indicated by medium to high resistivity zone at the alluvium-weathered bedrocks boundary. Alluvium was represented by intermediate resistivity values (8-100 Ωm), whereas weathered bedrock was represented by high resistivity values (100-400 Ωm). The deep aquifer or groundwater potential zone (PDL2) was interpreted in weathered bedrocks at 150 m depth. Thus, the proposed drilling location for PDL2 was at a 220 m survey line, with a minimum depth of 150 m for drilling.

3.3 Groundwater Abstraction

The aquifer characteristics were determined by performing a pumping test analysis, which included step drawdown test analysis and constant yield analysis after the drilling process had been completed. These tests were carried out for tube wells 1 and 2 at Kapar Power Plant.

3.3.1 Step Drawdown Test Analysis

Table 4 shows the pumping rate (Q), drawdown response data and Sw/Q values in tube wells 1 and 2. The study found that the Sw/Q values decreased with the increasing Q values, with transmissivity (T value) of 0.44 m^2/day. For tube well 2, the Sw/Q value has also decreased with the increasing Q values, with transmissivity (T value) of 0.16 m^2/day. According to JICA (1984), if the aquifer has a low T value (0 to 15 m^2/day), it is classified as a poor aquifer or low flowing rate [12]. The static water level for Well 1 and Well 2 are 2.54 meters b.g.l and 3 meters b.g.l, respectively. The C values for both tube wells are negative, indicating the non-linear groundwater flow in the wells.

Table 4. Pumping Rate (Q), drawdown response and Sw/Q values in tube well 1 and tube well 2.

Pumping Rate, Q in (m^3/day)	Duration of Pumping (minutes)	Tube Well 1		Tube Well 2	
		Drawdown recorded in tube well 1 (m)	Sw/Q (m^2/day)	Drawdown recorded in tube well 1 (m)	Sw/Q (m^2/day)
18.96	60	8.67	0.457278	11.40	0.07274
28.8	120	8.18	0.457278	3.1	0.01650
38.64	180	5.14	0.284028	0.45	0.00218
67.68	240	11.06	0.133023	1.58	0.00675
108.72	300	18.04	0.163416	3.8	0.01481

3.3.2 Constant yield test analysis

The final water level recorded at 2 hours after the pumping activity was stopped was 5.59 meters b.g.l. Due to the short test duration, the water level in Well 1 had yet to be fully recovered to the initial static water level of 2.54 meters b.g.l. The residual drawdown against t/t' plot was plotted, however, due to the bore storage effect, the transmissivity (T value) could not be derived from the plot. Meanwhile, water in Well 2 was fully recovered at 1 hour after the pumping activity was stopped. The final water level was 5.64 m. A fast recovery was expected since the water level dropped only 23.53 m throughout the pumping. The fast water recovery was due to the nearby water recharge source. Based on the plot, the transmissivity (T) value was 20.3 m^2/day.

The T (19 m^2/day) and K (0.67 m/day) values for Well 2 were obtained from all pumping test analyses (step drawdown test, constant yield test, and recovery test analysis). However, the T value for Well 1 was obtained from the step drawdown test analysis alone (less accurate). The negative C values obtained from the step drawdown test analysis for both wells indicated that these wells were poorly developed.

3.3.3 Water Quality Assessment

The purpose of water quality assessment is to determine the suitability of water use and the design of treatment to eliminate the contaminants in the groundwater. The groundwater from tubes wells 1 and 2 were collected and have been sent for laboratory analysis for a total of 42 parameters. Table 5 shows the parameters that should be eliminated from both tube wells before being utilized for AWR, cleaning, or gardening.

Table 5. Water quality analysis for tube wells 1 and 2.

No.	Parameters	Tube Well 1	Tube Well 2	MOH Standard	
				Raw	Drinking
1	**Total Dissolved Solids (ppm)**	574	355	1500	1000
2	**Total Hardness as $CaCO_3$ (mg/L)**	167	124	500	500
3	**Chloride (mmol/L)**	202	82	250	250
4	**Chemical Oxygen Demand (mg/L)**	46	22	10	-
5	**Biochemical Oxygen Demand (mg/L)**	15	8	6	-
6	**Ammonia (µmol/L)**	2.13	0.30	1.5	1.5
7	**Iron (mmol/L)**	2.26	1.05	1	0.3

Table 6 shows the trending of the water quality index (WQI) for both tube wells and the WQI values according to the Weight Arithmetic Water Quality Index (WQI) Method. The changes in grading are due to the duration of pumping activities.

Table 6. WQI for tube wells 1 and 2.

Date	Pumping Duration	Tube well	WQI	Rating of water quality	Grading
09.04.2017	72 hours	1	58	Poor Water Quality	C
11.08.2017	No pumping	1	124	Unsuitable for drinking	E
15.08.2017	2 hours	1	107	Unsuitable for drinking	E
16.08.2017	2 hours	1	90	Very Poor Water Quality	D
03.08.2017	72 hours	2	37	Good Water Quality	B
11.08.2017	No pumping	2	44	Good Water Quality	B
15.08.2017	2 hours	2	151	Poor Water Quality	C
16.08.2017	2 hours	2	33	Good Water Quality	B

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Based on the grading of water quality, Well 2 has good water quality compared to Well 1. WQI for both water tube wells was E - unsuitable for drinking purposes and C - poor water quality when there is no pumping activity. However, the WQI values showed good water quality when tube wells ran daily and poor water quality when the tube wells had no pumping activity.

4 Conclusion

It can be concluded that the area of Kapar Power Plant has the potential for groundwater abstraction that can be utilized as an alternative source of water. However, it has limitations whereby the quantity of water is too low compared to other potential sources of water for reclamation, such as industrial treated wastewater which has a bigger volume. In addition, the groundwater quality also did not meet Malaysian Drinking Water Standards due to the high concentrations of a few parameters such as Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), ammonia, iron and coliform. The utilization of groundwater from both tube wells 1 and 2 is not suitable for power plant purposes such as for drinking water, auxiliary equipment, watering and general cleaning. The WQI for both tube wells is similar to class III of surface water, whereby the groundwater contamination is due to the unconfined aquifer. Hence, further treatment is required in order to utilize the groundwater for the application within the power plant. Membrane technology was recommended to treat both tube wells as it is easy to operate, has less chemical usage, has low maintenance cost and is environmentally friendly.

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