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Water Quality Changes in Chini Lake, Pahang, West Malaysia

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Abstract A study of the water quality changes of Chini Lake was conducted for 12 months, which began in May 2004 and ended in April 2005. Fifteen sampling stations were selected representing the open water body in the lake. A total of 14 water quality parameters were measured and Malaysian Department of Environment Water Quality Index (DOE-WQI) was calculated and classified according to the Interim National Water Quality Standard, Malaysia (INWQS). The physical and chemical variables were temperature, dissolved oxygen (DO), conductivity, pH, total dissolved solid (TDS), turbidity, chlorophyll-a, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solid (TSS), ammonia-N, nitrate, phosphate and sulphate. Results show that base on Malaysian WQI, the water in Chini Lake is classified as class II, which is suitable for recreational activities and allows body contact. With respect to the Interim National Water Quality Standard (INWQS), temperature was within the normal range, conductivity, TSS, nitrate, sulphate and TDS are categorized under class I. Parameters for DO, pH, turbidity, BOD, COD and ammonia-N are categorized under class II. Comparison with eutrophic status indicates that chlorophyll-a concentration in the lake was in mesotrophic condition. In general water quality in Chini Lake varied temporally and spatially, and the most affected water quality parameters were TSS, turbidity, chlorophyll-a, sulphate, DO, ammonia-N, pH and conductivity.

Keywords Lake Chini · Water quality index (WQI) · Malaysia · Water quality · Natural lake

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1 Introduction

Chini Lake is the second largest natural lake in Peninsular Malaysia, located in the state of Pahang. Chini Lake which also acts as a wetland is important in natural ecosystems as its can help in reducing the frequency, level and velocity of floods and riverbank erosion. Wetland can act as natural sponges that absorb floodwater, and help protect adjacent and downstream areas from flood damage. It can also help recharge groundwater aquifers by holding water and allowing it to infiltrate the ground slowly. Chini Lake wetland plays an important role in providing fisheries as a source of revenue to the local people. It also provides an avenue for breeding, spawning and nursery grounds for both resident and migratory fish species. Chini Lake is drained by Chini River, which meanders for 4.8 km before flowing into Pahang River, the longest river in Peninsular Malaysia. In 1995, a small barrage about 2 m height was

constructed downstream of Chini River to hold the lake water for tourism purposes. Therefore, the water level of the lake has risen and became stagnant. This has changed the ecosystem of the Chini Lake from semi-lotic to lentic system. The adverse effects due to these changes were damages to the plant community, aquatic ecosystems and increased sedimentation rates in the lake. The wetland functions provided by the swamp forest to Chini Lake such as water purification and pollution retention are lost, and this may affect water quality in the lake (Lim & Shuhaimi-Othman, 2005; Shuhaimi-Othman, Lim, Mushrifah, & Shaharudin, 2005; Wetland International, 1998). Studies have shown that dams can disrupt the structure and function of river ecosystems by modifying flow regimes, disrupting sediment transport, altering water quality, and severing their biological continuity (Collier, Webb, & Schmidt, 1996; Petts, 1984).

Such conditions have raise concerns on deterioration in water quality of the lake. A study of water quality trends in 1992, 1993 and 1998 showed deterioration in some physical aspects of water quality such as temperature (increased about 2°C) (Idris & Abas, 2005). Abas, Othman, and Barzani Gasim (2005) classified Chini Lake as a mesotrophic lake according to the study conducted in 1999 and Ainon, Ratuah, Mimi, and Affendi (2006) have found that the lake water was threaten by excessive growth of bacteria (total coliform and faecal coliform), which are not safe for drinking. The lake which once was famous with the lotus *Nelumbo nucifera* and water lily was also invaded by an aquatic weed call 'cat tail' or *Cabomba furcata* which slowly replacing the lotus as dominant plant species in the lake.

In recent years, Chini Lake experienced major development in agriculture activities. Large areas of forest were converted to oil palm plantation. Illegal logging activities also contributed to the lost of forest area. Agriculture activities were believed to release pollutant such as nitrate and phosphate into the lake. Soil erosion generated by the conversion of forest to agriculture land and logging activities in this area was believed as one of the main contribution to the increase of suspended solid concentration in the river and lake water body (Barzani Gasim, Sahibin, Shuhiami Othman, & Ang, 2005). The construction of National Service Centre for National Service Training programme in Chini Lake since 2004 also contributed to the increase in nutrient and organic loading into the lake. Therefore it is important that a study is conducted to assess the trend of water quality changes in the lake for sustainable management.

This study was conducted for the duration of 12 months, which began in May 2004 and ended in April 2005. A total of 14 water quality parameters were measured and Malaysian Department of Environment–Water Quality Index (DOE-WQI) was calculated and classified by Interim National Water Quality Standard (INWQS) (DOE, 2002; Tong & Goh, 1997). The aim of this study is to determine the changes of Chini Lake's water quality within 12 months in association to the seasonal variation and other activities occurring around the lake vicinity.

2 Materials and Methods

2.1 Study area and sampling stations

Chini Lake is made up of a series of 12 lakes or opened water body recognized as 'seas' by local residents. The 12 'seas' are Gumum, Pulau Balai, Cenahan, Tanjung Jerangking, Genting Teratai, Mempitih, Kenawar, Serodong, Melai, Batu Busuk, Labuh and Jemberau (Figure 1). In present study, 15 sampling stations (1–15) were selected to cover all areas of the lake (Figure 1) and the GPS position for each sampling station is shown in Table II. A total of seven feeder rivers from the basin area were identified as the main source of water inputs into the lake (Tan & Barzani Gasim, 2005) such as Datang River in the Northwest, Gumum River in the Northeast, Perupok River in the West and Melai River in the South. The basin area of Chini Lake received a total rainfall of 2,192.0 mm in year 2004 and 2,260.2 mm in year 2005 (MMS, 2005). Topographically, the lake is surrounded by low hills and undulating land which constitute the catchment of the region. The area of Chini Lake varies from 150 to 350 ha, depends on the season changes and 700 ha of freshwater swamp and swamp forest (Chong, 2001). The volume of water in Chini Lake was estimated between 4×10^6 to 7×10^6 m^3 and the mean inflow discharge between 0.46 to 3.53 $m^3\ s^{-1}$ (Tan & Barzani Gasim, 2005).

The climate of Lake Chini is typical of the equatorial climate of Peninsular Malaysia, which is characteristic by moderate average annual rainfall, temperature and humidity. In normal season, water

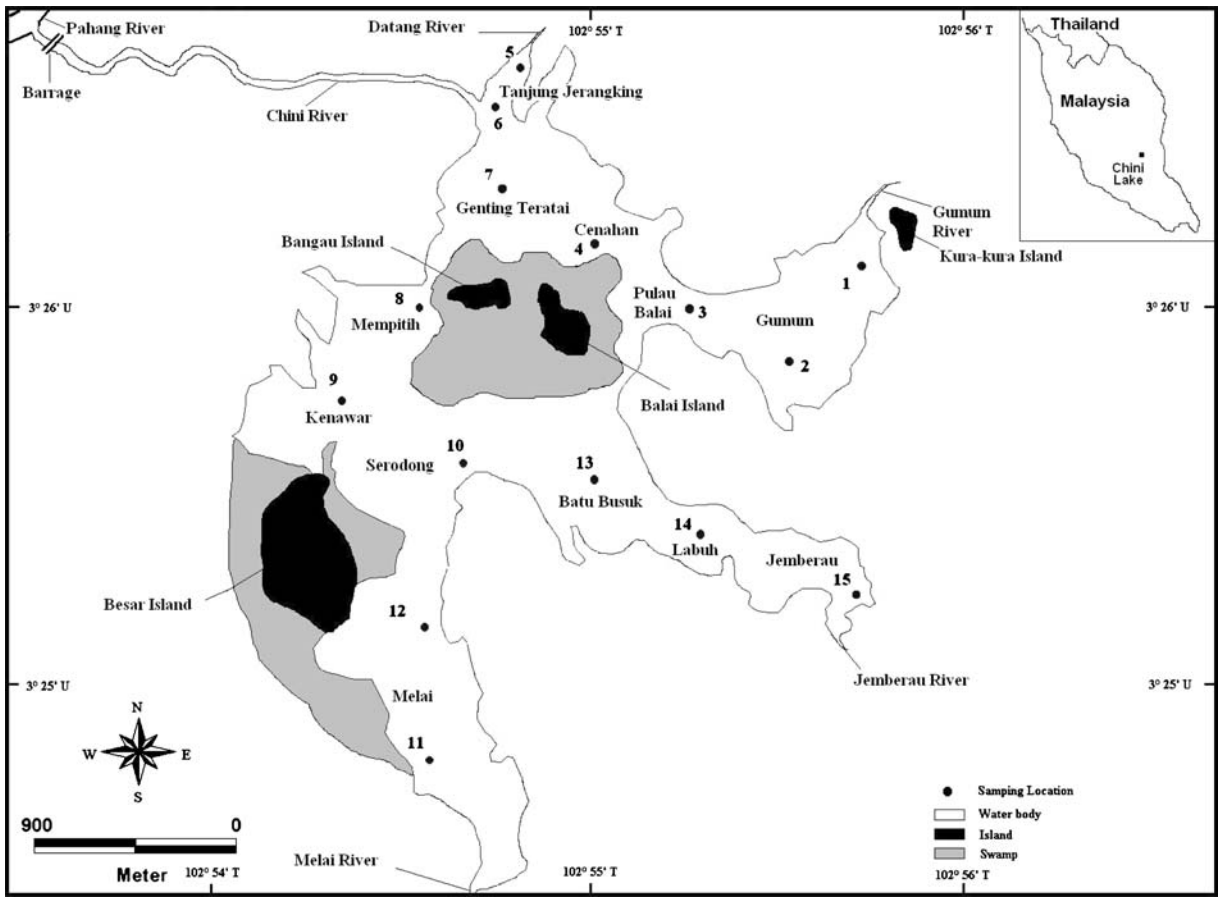

Figure 1 Location of Chini Lake and the sampling stations.

will flow from the Chini Lake into the Pahang River through Chini River. In dry season, no flow into the Pahang River from the lake and Chini River because of the water level in Chini River is lower than the barrage. However, during the raining season the overflowing of Pahang River together with the reverse flow of the flood water into Chini River and Chini Lake resulted flooding in the river and lake. During our 12 field trips to Chini Lake, we have experienced twice flooding in the lake (October and December of 2004). Some areas of forest land located at the east of the Chini Lake were also converted to agriculture land such as rubber and oil palm plantation (estimated about 807 ha, unpublished data) and logging activity (estimated about 67 ha, unpublished data) is still active in the north-east of the lake. An abandon mine was also reactivated with the iron-mining activities in the early 2005. At the east of the lake (Gumum area), there are a village for the settlement of the indigenous people, a resort and a National Service Centre camp.

2.2 Sampling

Field sampling was conducted monthly which began from June 2004 to May 2005. Surface water was collected from each station (three replicates) in HDPE bottle 500 ml for laboratory analysis (*ex situ*) i.e., phosphate (PO_4^{3-}), nitrat (NO_3^-), ammonia-N (NH_3–N), sulphate (SO_4^{2-}), chemical oxygen demand (COD) and total suspended solid (TSS). Biochemical oxygen demand (BOD) was sampled using dark BOD bottle 300 ml. All the samples were kept in the dark and cool (temperature 4–6°C) in the cool box.

2.3 *In situ* parameters

Three replicates of the chemical and physical variables of the lake were measured directly at each sampling station using HYDROLAB DataSonde® 4 and Surveyer® 4a. These were temperature, dissolved oxygen (DO), conductivity, pH, total dissolved solid (TDS),

Table I Mean water quality parameters and WQI (max–min) for 15 sampling stations in Chini Lake (June 2004–May 2005)

	Year 2004							Year 2005				
	June	July	August	September	October	November	December	January	February	March	April	May
Temperature (°C)	30.26 (28.97–31.06)	29.39 (28.75–29.88)	30.03 (29.72–30.41)	29.79 (29.27–30.68)	28.66 (27.01–29.96)	28.95 (28.01–29.98)	27.28 (25.44–28.16)	27.58 (27.17–28.13)	30.27 (28.57–31.35)	30.50 (29.46–31.60)	31.15 (30.06–32.19)	31.39 (30.72–32.10)
Conductivity ($\mu S\ cm^{-1}$)	22.58 (15.48–30.25)	20.83 (14.98–29.45)	21.55 (15.75–33.05)	21.72 (15.93–30.20)	27.29 (22.50–40.28)	23.39 (19.08–29.16)	23.55 (20.30–30.75)	22.90 (20.28–30.13)	24.69 (19.78–40.35)	25.60 (19.45–45.65)	28.99 (19.82–48.98)	31.19 (23.04–50.83)
TDS ($mg\ l^{-1}$)	14.4 (9.9–19.4)	13.3 (9.6–18.8)	13.8 (10.1–21.2)	13.9 (10.2–19.3)	17.5 (14.4–25.8)	14.9 (12.2–18.5)	15.1 (13.0–19.7)	14.7 (13.0–19.3)	15.8 (12.7–25.8)	16.4 (12.4–29.2)	18.5 (12.7–31.4)	19.9 (14.72–32.53)
DO ($mg\ l^{-1}$)	5.41 (4.51–6.38)	6.13 (4.57–7.18)	6.25 (4.35–7.12)	5.88 (2.61–6.98)	5.10 (2.91–7.44)	4.11 (1.91–7.69)	5.83 (4.90–7.34)	5.23 (4.38–7.22)	5.64 (4.49–6.53)	6.77 (5.56–7.49)	6.56 (5.23–7.92)	6.54 (3.83–7.60)
pH	6.33 (6.01–6.64)	6.63 (6.22–6.83)	6.62 (6.06–7.15)	6.63 (5.90–6.99)	6.52 (6.11–6.84)	6.59 (6.27–6.76)	6.56 (6.18–6.89)	6.23 (5.86–6.36)	6.52 (6.08–6.91)	6.31 (5.82–6.67)	6.34 (5.72–6.95)	6.61 (5.78–7.38)
Chl-a ($\mu g\ l^{-1}$)	0.42 (0.13–0.64)	1.76 (0.50–3.66)	21.91 (8.58–34.53)	0.97 (0.24–2.61)	1.03 (0.31–1.76)	0.66 (0.30–1.15)	0.88 (0.37–1.31)	1.09 (0.42–1.46)	1.06 (0.31–1.51)	1.65 (0.46–2.59)	1.55 (0.28–2.42)	1.75 (0.38–2.62)
Turbidity (NTU)	1.54 (0.00–3.05)	1.59 (0.00–6.40)	6.17 (0.70–13.20)	0.78 (0.00–6.57)	38.29 (0.00–374.15)	4.17 (0.00–24.63)	32.31 (0.00–130.95)	1.38 (0.00–16.93)	6.92 (0.00–15.94)	0.29 (0.00–2.68)	109.13 (60.30–156.23)	0.00
BOD ($mg\ l^{-1}$)	1.71 (0.61–3.00)	3.55 (2.27–5.29)	1.62 (0.83–2.55)	0.73 (0.03–1.50)	1.33 (0.80–2.13)	1.61 (0.81–2.45)	0.78 (0.26–1.89)	0.74 (0.22–1.13)	1.01 (0.38–2.73)	1.58 (0.79–2.52)	1.69 (0.74–2.95)	1.89 (0.61–2.87)

COD (mg l^{-1})	13.29 (7.95–17.35)	15.68 (9.65–20.70)	16.85 (10.15–24.55)	17.53 (8.95–26.50)	12.90 (6.25–21.65)	19.94 (16.30–22.40)	12.85 (7.40–17.70)	14.07 (11.75–16.30)	14.73 (9.00–21.85)	19.45 (10.05–22.80)	17.88 (7.05–23.80)	22.76 (9.35–29.85)
TSS (mg l^{-1})	4.51 (1.33–8.50)	4.31 (0.50–11.00)	5.27 (0.67–14.33)	5.99 (1.00–13.17)	11.36 (0.50–97.22)	7.11 (1.67–16.83)	29.78 (1.67–74.17)	8.45 (1.75–18.25)	6.49 (0.56–12.27)	9.93 (1.33–17.06)	4.62 (0.50–8.50)	6.87 (1.33–12.00)
NH_3N (mg l^{-1})	0.132 (0.067–0.337)	0.120 (0.057–0.183)	0.092 (0.020–0.163)	0.108 (0.040–0.187)	0.308 (0.097–1.180)	0.221 (0.077–0.360)	0.407 (ND–.0897)	0.225 (0.047–0.597)	0.059 (ND–0.170)	0.148 (0.073–0.237)	0.051 (0.010–0.093)	0.117 (0.023–0.197)
Nitrate (mg l^{-1})	0.006 (0.00–0.010)	0.025 (0.010–0.153)	0.016 (0.003–0.037)	0.009 (0.00–0.020)	0.315 (0.047–1.840)	0.036 (0.003–0.220)	0.027 (0.00–0.067)	0.219 (0.117–0.330)	0.032 (0.007–0.190)	0.567 (0.043–1.913)	0.012 (0.003–0.033)	0.706 (0.093–1.693)
Phosphate (mg l^{-1})	0.048 (0.030–0.060)	0.053 (0.040–0.077)	0.041 (0.023–0.083)	0.052 (0.033–0.110)	0.051 (0.010–0.100)	0.090 (0.047–0.357)	0.077 (0.013–0.110)	0.048 (0.007–0.093)	0.062 (0.037–0.080)	0.062 (0.033–0.100)	0.080 (0.057–0.107)	0.083 (0.060–0.123)
Sulphate (mg l^{-1})	0.311 (0.00–0.667)	0.556 (0.00–1.000)	ND	0.400 (0.00–0.667)	0.487 (0.00–1.333)	0.489 (0.00–1.333)	0.159 (0.00–0.333)	0.190 (0.00–0.667)	0.0267 (0.00–0.667)	0.569 (0.00–1.667)	0.561 (0.00–3.333)	2.00 (0.00–9.00)
WQI[a]	87.78 (82.98–91.17)	88.08 (81.72–91.65)	90.12 (80.22–95.22)	88.62 (65.14–95.03)	84.19 (72.70–94.75)	79.64 (69.69–93.31)	84.91 (77.25–95.40)	85.13 (80.31–93.44)	90.16 (85.85–94.91)	89.65 (85.39–93.22)	91.31 (86.03–94.37)	89.28 (79.20–93.41)
Rainfall (mm)	5.43 (0.00–64.20)	5.60 (0.00–45.00)	2.20 (0.00–22.10)	7.45 (0.00–46.10)	17.9 (0.00–149.90)	6.44 (0.00–73.50)	7.90 (0.00–70.20)	2.60 (0.00–44.20)	1.00 (0.00–5.30)	7.48 (0.00–33.10)	4.20 (0.00–29.00)	5.90 (0.00–98.80)

[a] Class I=>92.7; Class II=76.5–92.7; Class III=51.9–76.5; Class IV=31.0–51.9; Class V=<31.0

ND Not detected

turbidity and chlorophyll-a concentration. Calibration of every HYDROLAB DataSonde® 4 probes was conducted in the laboratory before field sampling.

2.4 Laboratory analysis (*ex situ* parameters)

All the samples collected from the field were kept in a refrigerator at a temperature below 4°C to reduce all the activities and metabolism of the organisms in the water. The BOD, COD, TSS, ammonia-N (total), nitrate, phosphate and sulphate were measured in accordance with the standard method procedures (APHA, 1992; HACH, 2003). The COD, ammonia-N, nitrate, phosphate and sulphate were determined by using a spectrophotometer Model HACH DR 2500 at a specified wavelength (APHA, 1992; HACH, 2003). Six water quality parameters i.e.,, DO, BOD, COD, TSS, ammonia-N and pH were used in the calculation of DOE-Water Quality Index (DOE-WQI) as described by Norhayati, Goh, Tong, Wang, and Abdul Halim (1997). The index is based on DOE opinion poll WQI and computed from the equation:

$$\begin{aligned}\mathrm{WQI} = {} & 0.22\,(\mathrm{SI\,DO}) + 0.19\,(\mathrm{SI\,BOD}) \\ & + 0.16\,(\mathrm{SI\,COD}) + 0.15\,(\mathrm{SI\,AN}) \\ & + 0.16\,(\mathrm{SI\,SS}) + 0.12\,(\mathrm{SI\,pH})\end{aligned}$$

where SI refers to the sub index function for each of the given parameters and the coefficients are the weighting factors derived from the opinion poll.

2.5 Statistical Analysis

Statistical analysis was conducted by one-way ANOVA and Tukey–Kramer multiple comparison tests using the statistical package Minitab (Vers. 12). Data were tested for normality (Shapiro–Wilk test) and homogeneity (Barlett's χ^2) and to meet these requirements, data were log10 transformed. Regression analyses were used to test the relationship between chemical and physical variables.

3 Results

The monthly mean of the parameters measured from 15 sampling stations in this study is shown in Table I. The mean (for 12 months sampling) and range (maximum to minimum) for *in situ* and *ex situ* parameters for 15 sampling stations are shown in Tables II and III. Statistical analysis (ANOVA; Tukey Kramer) shows that all parameters measured in this study have significant differences ($P<0.01$) between the sampling months. Those variations in water quality parameters were mainly due to seasonal changes (wet or drought season) and anthropogenic activities. Correlation analysis was also conducted to examine the relationship between different variables (Table IV). Because of the large number of correlation run (n=180), several of these will be expected to come up significant by chance alone. Hence, only the ones at $P<0.001$ should be accepted as 'truly significant' and the others ($P<0.01$ and $P<0.05$) should be viewed as possibly significant relationships.

3.1 Rainfall

The rainfall through the sampling period was acquired from Malaysia Meteorological Centre (MMS) (Table I). From June 2004 to May 2005, 2,095.69 mm of rainfall was recorded in Chini Lake (MMS, 2005). October 2004 recorded the highest precipitation (553.5 mm) and the number of raining days (21 days), as the start of the raining season (Oct–Dec). The monthly rainfall has shown significant negative relationship with parameters such as temperature(r=−0.398, $P<0.001$), dissolved oxygen (DO) (r =−0.483, $P<0.001$) and chlorophyll-a concentration (r=−0.448, $P<0.001$) while positively correlation with ammonia nitrogen (r=0.387, $P<0.001$) (Table IV).

3.2 Temperature

The mean water temperature for 12 months sampling was 29.60±1.29°C, which ranged from 25.44°C to 32.19°C. The stagnant lake water was able to retain heat in the water, therefore during low precipitation months, the water temperature exceeded 30°C. The water temperature shows downward trend from September 2004 to January 2005 due to high precipitation rate. Large volume of water inputs and higher flow rate were responsible to cool down the lake water temperature. Correlation analysis showed that temperature has a negative significant relationship with the rainfall (r=−0.398, $P<0.001$).

Table II Mean, range and SD for *in situ* parameters for 15 sampling stations for 12 months period (June 2004–May 2005)

Station (GPS position)		Temperature,°C	Conductivity ($\mu S\ cm^{-1}$)	TDS ($mg\ l^{-1}$)	DO ($mg\ l^{-1}$)	pH	Chlorophyll-a ($\mu g\ l^{-1}$)	Turbidity (NTU)
1	Mean	29.38	23.97	15.34	6.31	6.53	3.68	19.71
03°26′07.34″N	Range	26.83–31.17	21.53–29.10	13.80–18.66	4.67–7.18	6.24–6.77	0.62–24.97	0–157.85
102°55′47.48″E	SD	1.44	2.58	1.66	0.74	0.20	6.74	44.21
2	Mean	29.52	24.15	15.45	6.10	6.52	3.60	14.96
03°25′ 55.56″N	Range	27.23–31.22	21.65–29.38	13.85–18.82	4.22–7.12	6.19–6.81	0.64–24.98	0–130.80
102° 55′ 40.50″E	SD	1.40	2.64	1.68	0.81	0.21	6.78	36.80
3	Mean	29.40	24.09	15.42	5.65	6.38	3.43	20.87
03°26′00.99″N	Range	26.91–31.13	21.75–27.73	13.93–17.73	4.38–6.72	6.06–6.69	0.47–25.00	0–145.76
102°55′20.58″E	SD	1.33	2.07	1.32	0.81	0.25	6.84	43.01
4	Mean	29.49	22.75	14.55	5.98	6.48	3.37	20.71
03°26′10.67″N	Range	26.43–31.25	19.30–25.73	12.33–16.47	4.03–7.23	6.10–6.76	0.42–25.02	0–147.25
102°55′06.52″E	SD	1.52	2.21	1.42	1.02	0.20	6.85	43.42
5	Mean	29.03	21.83	13.97	4.09	6.06	3.14	26.92
03°26′32.00″N	Range	25.44–30.72	17.17–29.83	10.97–19.05	2.57–6.13	5.72–6.82	0.44–25.02	0–121.77
102°54′51.29″E	SD	1.49	4.08	2.60	1.04	0.49	6.91	46.26
6	Mean	29.15	23.50	15.03	5.13	6.32	3.35	57.63
03°26′37.47″N	Range	26.02–30.99	17.65–40.28	11.25–25.75	1.91–6.06	5.91–6.89	0.51–25.02	0–374.15
102°54′57.8″E	SD	1.57	6.24	3.98	1.10	0.32	6.86	113.31
7	Mean	29.71	21.18	13.55	5.89	6.54	3.22	17.35
03°26′19.07″N	Range	27.21–31.50	16.63–26.48	10.63–16.95	2.97–7.49	6.30–6.76	0.57–25.03	0–117.85
102°54′52.21″E	SD	1.34	3.11	1.98	1.33	0.16	6.89	34.81
8	Mean	29.83	19.41	12.42	5.92	6.62	2.68	12.32
03°26′02.72″N	Range	27.66–31.44	14.98–27.30	9.58–17.48	2.55–7.21	6.35–6.91	0.46–19.06	0–92.42
102°54′44.23″E	SD	1.27	3.56	2.28	1.26	0.18	5.19	28.37
9	Mean	29.96	20.10	12.85	5.88	6.63	2.81	10.64
03°25′47.93″N	Range	27.85–31.58	15.83–27.78	10.13–17.75	3.23–7.12	6.35–6.86	0.39–20.92	0–85.60
102°54′35.53″E	SD	1.20	3.76	2.40	1.17	0.17	5.72	25.41
10	Mean	29.71	23.44	15.00	5.70	6.58	3.24	9.45
03°25′36.34″N	Range	27.41–32.10	19.05–35.43	12.15–22.70	3.16–7.31	6.11–6.92	0.45–25.03	0–93.69
102°54′46.39″E	SD	1.38	4.61	2.95	1.31	0.24	6.88	26.64
11	Mean	29.81	26.66	17.05	5.74	6.56	3.96	6.63
03°24′57.68″N	Range	27.84–31.94	19.48–43.10	12.50–27.50	3.60–7.31	6.34–6.89	0.374–34.53	0–61.80
102°54′40.71″E	SD	1.30	6.79	4.34	1.19	0.19	9.63	17.54
12	Mean	29.87	26.53	16.99	5.86	6.65	3.26	7.10
03°25′05.93″N	Range	27.60–31.65	20.08–43.46	12.80–27.82	4.32–7.49	6.28–7.15	0.48–26.92	0–71.80
102°54′41.17″E	SD	1.35	6.79	4.35	1.17	0.26	7.46	20.45
13	Mean	30.35	29.98	19.18	6.12	6.67	1.44	9.89
03°25′36.38″N	Range	28.13–32.20	24.75–38.60	15.83–24.70	4.96–7.75	6.18–7.38	0.23–9.04	0–101.90
102°55′12.12″E	SD	1.28	4.28	2.74	0.89	0.30	2.44	29.24
14	Mean	29.71	35.31	22.58	5.69	6.54	1.13	6.86
03°25′27.09″N	Range	27.24–31.69	26.97–50.83	17.27–32.53	4.62–6.68	6.31–6.80	0.16–9.54	0–76.35
102°55′25.63″E	SD	1.31	8.69	5.57	0.57	0.15	2.65	21.90
15	Mean	29.15	24.48	15.65	6.54	6.21	1.11	11.64
03°25′17.42″N	Range	27.09–31.58	21.00–28.00	13.40–17.93	5.20–7.69	5.82–6.59	0.13–8.58	0–72.80
102°55′48.18″E	SD	1.17	2.66	1.72	0.84	0.23	2.36	24.84

SD Standard deviation

Table III Mean, range and SD for *ex situ* parameters and WQI for 15 sampling stations for 12 months period (June 2004–May 2005)

Station		BOD (mg l^{-1})	COD (mg l^{-1})	TSS (mg l^{-1})	NH_3–N (mg l^{-1})	NO^{3-} (mg l^{-1})	PO_4^{3-} (mg l^{-1})	SO_4^{2-} (mg l)	WQI[a]
1	Mean	1.95	19.37	11.78	0.217	0.142	0.082	0.181	87.16
	Range	0.94–4.64	13.70–26.50	6.67–18.25	0.080–0.397	0.003–0.673	0.010–0.357	0.000–1.000	79.69–90.98
	SD	0.96	4.06	3.89	0.095	0.224	0.090	0.344	3.46
2	Mean	1.55	18.90	11.50	0.221	0.348	0.055	0.222	87.28
	Range	0.80–4.16	13.05–24.00	5.89–17.5	0.063–0.597	0.003–1.913	0.013–0.107	0.000–1.000	78.19–90.96
	SD	0.92	3.62	3.66	0.140	0.717	0.031	0.328	4.06
3	Mean	1.68	17.57	9.45	0.176	0.221	0.058	0.292	86.37
	Range	0.30–5.29	9.90–24.95	4.17–18.67	0.093–0.327	0.003–1.693	0.037–0.097	0.000–1.000	80.31–90.07
	SD	1.23	4.40	4.31	0.080	0.475	0.018	0.349	3.40
4	Mean	1.69	16.73	11.28	0.196	0.226	0.068	0.250	87.28
	Range	0.69–4.14	10.15–26.45	4.33–46.67	0.063–0.637	0.003–2.000	0.043–0.110	0.000–0.667	78.67–91.74
	SD	0.94	4.85	11.41	0.153	0.570	0.022	0.280	4.33
5	Mean	1.44	14.79	13.44	0.212	0.120	0.061	0.306	79.71
	Range	0.26–3.22	7.40–21.25	2.83–72.72	0.027–0.803	0.000–0.387	0.027–0.097	0.000–1.000	65.14–86.58
	SD	0.83	4.40	19.40	0.220	0.157	0.020	0.354	6.72
6	Mean	1.61	15.81	21.71	0.289	0.206	0.062	0.236	83.59
	Range	0.66–3.18	5.15–24.50	6.5–97.22	0.063–1.180	0.003–1.610	0.043–0.100	0.000–1.000	69.69–89.55
	SD	0.81	5.61	30.38	0.360	0.459	0.020	0.337	6.13
7	Mean	1.64	17.29	12.44	0.178	0.089	0.054	0.417	86.63
	Range	0.50–3.47	9.60–28.30	5.33–61.50	0.040–0.543	0.003–0.330	0.007–0.090	0.000–1.667	75.64–92.23
	SD	0.72	5.02	15.77	0.140	0.113	0.026	0.510	5.44
8	Mean	1.59	18.68	7.89	0.153	0.073	0.062	0.389	87.94
	Range	0.42–2.87	11.30–29.85	0.67–42.22	0.003–0.513	0.000–0.267	0.023–0.100	0.000–1.333	71.94–93.29
	SD	0.83	5.51	11.21	0.138	0.107	0.028	0.529	5.83
9	Mean	1.70	18.31	7.96	0.148	0.123	0.066	0.264	87.83
	Range	0.62–3.67	12.90–28.70	1.33–43.67	0.017–0.507	0.003–0.740	0.030–0.123	0.000–2.000	77.16–92.91
	SD	0.95	4.54	11.50	0.131	0.215	0.024	0.575	5.08
10	Mean	1.63	19.25	6.08	0.149	0.064	0.060	0.667	86.85
	Range	0.58–3.24	13.50–23.85	2.33–20.89	0.023–0.400	0.000–0.277	0.027–0.087	0.000–5.667	73.09–92.04
	SD	0.84	3.31	4.93	0.112	0.099	0.019	1.621	5.77
11	Mean	1.77	18.63	4.96	0.143	0.240	0.062	1.181	87.22
	Range	0.31–3.26	14.85–22.35	2.17–10.17	0.020–0.357	0.000–2.267	0.037–0.100	0.000–8.333	78.19–91.99
	SD	0.90	2.39	2.00	0.085	0.644	0.017	2.443	4.73
12	Mean	1.38	17.87	6.18	0.165	0.072	0.059	1.097	87.68
	Range	0.56–3.22	14.50–22.40	2.67–13.67	0.023–0.343	0.000–0.333	0.023–0.083	0.000–9.000	80.77–92.90
	SD	0.85	3.18	3.42	0.101	0.104	0.018	2.582	4.83
13	Mean	1.08	12.93	3.35	0.084	0.186	0.058	1.181	91.35
	Range	0.24–2.58	9.00–23.10	0.50–12.00	0.000–0.180	0.000–1.167	0.033–0.087	0.000–0.667	85.41–94.91
	SD	0.72	4.25	3.41	0.052	0.326	0.017	0.241	2.52
14	Mean	1.12	10.08	1.39	0.050	0.223	0.063	0.236	91.61
	Range	0.03–3.38	6.25–16.50	0.50–3.00	0.000–0.110	0.007–1.467	0.043–0.083	0.000–1.000	87.85–95.22
	SD	0.93	2.72	0.94	0.035	0.416	0.016	0.305	2.35
15	Mean	0.99	11.20	1.39	0.055	0.129	0.068	0.167	92.59
	Range	0.51–3.56	8.35–16.30	0.50–3.33	0.000–0.133	0.003–0.853	0.033–0.110	0.000–0.667	89.49–95.40
	SD	0.82	2.02	0.76	0.038	0.242	0.025	0.256	2.08

SD Standard deviation

[a] Class I=>92.7; Class II=76.5–92.7; Class III=51.9–76.5; Class IV=31.0–51.9; Class V=<31.0

Table IV Pearson correlation coefficient (r) between water quality parameters, WQI and the rainfall

	Temp.	Cond.	TDS	DO	pH	Chl-a	Turb.	NH_3 N	NO^{3-}	PO_4^{3-}	SO_4^{2-}	BOD	COD	TSS	WQI
Cond.	0.184*														
TDS	0.184*	1.000***													
DO	0.391***	0.093	0.092												
PH	0.141	0.084	0.084	0.272***											
Chl-a	0.177*	−0.232**	−0.232**	0.232**	0.166*										
Turb.	−0.045	0.116	0.116	0.065	−0.014	0.164*									
NH_3 N	−0.661***	−0.003	−0.003	−0.344***	0.053	−0.053	0.213**								
NO^{3-}	0.145	0.311***	0.310***	0.153*	−0.063	0.026	−0.258***	0.025							
PO_4^{3-}	0.095	0.235**	0.234**	−0.021	−0.016	−0.185*	0.216**	0.010	0.016						
SO_4^{2-}	0.145	0.311***	0.310***	0.153*	−0.063	0.026	−0.258***	0.025	1.000***	0.066					
BOD	0.321***	−0.161*	−0.162*	0.085	−0.077	0.335***	0.013	−0.091	0.052	0.029	0.052				
COD	0.355***	−0.240**	−0.241**	0.110	0.086	0.409***	−0.132	−0.134	0.138	0.096	0.138	0.400***			
TSS	−0.321***	−0.179*	−0.179*	−0.079	0.042	0.199**	0.271***	0.679***	0.091	0.087	0.091	0.031	0.303***		
WQI	0.521***	0.153*	0.152*	0.866***	0.217**	0.102	−0.045	−0.665***	0.067	−0.061	0.067	−0.031	−0.064	−0.440***	
rainfall	−0.398***	0.010	0.009	−0.483***	0.069	−0.448***	−0.076	0.387***	−0.059	0.154*	−0.059	0.011	0.012	0.072	−0.517***

WQI Water Quality Index

*Indicates a significant relationship ($P<0.05$); **Indicates a significant relationship ($P<0.01$) ***Indicates a significant relationship ($P<0.001$)

3.3 Conductivity and total dissolved solid (TDS)

The mean conductivity in Chini Lake is 24.52± 3.19 μS cm^{-1}, which ranges from 14.98 to 50.83 μS cm^{-1}. The mean for TDS is 15.68±2.03 mg l^{-1} with values ranging from 9.6 to 32.53 mg l^{-1}. Conductivity and TDS was positively correlated with ion such as sulphate (r=0.311 and 0.310 respectively, $P<0.001$) and nutrient such as nitrate (r=0.311 and 0.310 respectively, $P<0.001$). The highest conductivity and TDS in 2004 was recorded in October with the values of 27.29 μS cm^{-1} and 17.5 mg l^{-1} respectively i.e., when the lake was flooded. In 2005, an upward trend was observed where the respective conductivity and TDS values increased from 22.90 μS cm^{-1} and 14.7 mg l^{-1} in January, to 31.19 μS cm^{-1} and 19.96 mg l^{-1} respectively, in May. The reactivation of the mining area located near station 11 and 12 (Melai) was probably the main contributing factor for such changes (Table II).

3.4 Dissolved oxygen (DO)

The DO concentration in Chini Lake ranges from 1.91 to 7.92 mg l^{-1} (25.9%–98.2%) with a mean value of 5.79±0.75 mg l^{-1} (78.6%). Chini Lake is a shallow lake with mean depth <2.5 m, so the influence of water depth is negligible. This study showed that the DO in the lake water was correlated with pH (r=0.272, $P<0.001$) and also with chlorophyll-a (r=0.232, $P<0.01$) and negative correlated with NH_3–N (r=−0.344, $P<0.001$) and the rainfall (r=−0.483, $P<0.001$). These results indicated that the main contributing factors for dissolved oxygen (DO) in Chini Lake are photosynthesis activities (chlorophyll-a), seasonal variable (wet or dry) and decomposition rate of organic matter (temperature and pH). Station 5 shows the lowest DO among the stations especially during the flooded months, followed by station 6, 7 and 8.

3.5 pH

The mean pH value in Chini Lake is 6.49±0.15, which ranges from 5.72 to 7.38. pH was shown to be the most stable parameter which did not show drastic changes among sampling months (Table II). Station 5, 6 and 15 showed low pH reading compared to other stations.

3.6 Chlorophyll-a

The mean chlorophyll-a concentration in Chini Lake is 2.89±6.00 μg l^{-1}, with values ranging from 0.13 to 34.53 μg l^{-1}. A significant upward trend of chlorophyll-a concentration was found from June to August 2004 (0.42–21.91 μg l^{-1}). A steady upward trend occurred from November 2004 (0.66 μg l^{-1}) to May 2005 (1.75 μg l^{-1}) which marked the transition from raining season to dry season.

3.7 Turbidity

Turbidity in Chini Lake has a mean value of 16.88± 31.78 NTU (Nephelometric Turbidity Unit), which ranges from 0.00 to 374.15 NTU. Correlation analysis showed that turbidity has a positive relationship with total suspended solid (TSS) (r=0.271, $P<0.001$). In 2004, the mean turbidity exceeded 30 NTU in October and December where Chini Lake was flooded by the Pahang River. However, the mean turbidity measured in April 2005 was inexplicably increased to 109.13 NTU and high concentration was recorded at all 15 sampling stations (60.30–156.23 NTU). Since the chlorophyll-a concentration and total suspended solid (TSS) were low in the month of April, there was probably other factors that contributed to the water turbidity that were not measured in this study. Lake Chini water's was found in reddish colour in April 2005 (visual observation) and this probably due to organic acid such as fulvic acid which has been reported could influenced the turbidity reading in water (Gippel, 1989). High monthly rainfall was also recorded in March and April compare to February (Table I) which could increase the leaching of organic content from the surrounding swamp into the lake water.

3.8 Biochemical oxygen demand (BOD)

The mean BOD in Chini Lake is 1.52±0.76 mg l^{-1}, which ranges from 0.03 to 5.25 mg l^{-1}. BOD value is positively correlated with chemical oxygen demand (COD) (r=0.400, $P<0.001$), chlorophyll-a concentration (r=0.335, $P<0.001$) and temperature (r=0.321, $P<0.001$).

3.9 Chemical oxygen demand (COD)

The mean chemical oxygen demand (COD) in Chini Lake is 16.88±2.95 mg l^{-1}, which ranges from 6.25 to 29.85 mg l^{-1}. COD was found to be correlated positively with temperature (r=0.355, $P<0.001$), BOD (r=0.400, $P<0.001$) and chlorophyll-a (r=0.409, $P<0.001$). In November 2004, a well-distributed pattern of chemical compounds was observed in the lake, as minimum variation of COD values was observed among the stations. This is probably due to the flood which started in October 2004. The COD values also experienced an upward trend in 2005 (Table I).

3.10 Total suspended solid (TSS)

The mean TSS in Chini Lake is 8.72±6.98 mg l^{-1}, with values ranging from 0.50 to 97.22 mg l^{-1}. It was strongly correlated with ammonia nitrogen (r=0.679, $P<0.001$) especially during flood period. Chlorophyll-a concentration was found slightly correlated with TSS (r=0.199, $P=0.007$). The abundant vegetations at the lake–land borders are believed to play an important role of filtering the soil particulates from entering the lake. Therefore, the TSS in lake water was low (<10 mg l^{-1}) excluding the flooded period.

3.11 Ammonia nitrogen

The mean ammonia nitrogen content in Chini Lake is 0.166±0.106 mg l^{-1}, which ranges from 0.00 to 0.597 mg l^{-1}. Ammonia nitrogen has shown strong positive relationship with rainfall (r=0.387, $P<0.001$) and total suspended solid (TSS) (r=0.679, $P<0.001$) while it is negative correlated with temperature (r=−0.661, $P<0.001$) and dissolved oxygen (DO) (r=−0.344, $P<0.001$). High concentration of ammonia in October and December 2004 coincided with high TSS contents when the lake was flooded. Pahang River water which flow into the lake through the Chini River might be enriches with ammonia and this generates these changes in Chini Lake.

3.12 Nitrate

The mean value for nitrate content in Chini Lake is 0.164±0.243 mg l^{-1}, which ranges from 0.00 to 1.84 mg l^{-1}. There was no significant trend of nitrate concentration in Chini Lake.

3.13 Phosphate

The mean content of phosphate in Chini Lake is 0.062±0.016 mg l^{-1}, which ranges from 0.007 to 0.123 mg l^{-1}. The phosphate level in Chini Lake was consistent throughout the sampling period (Table I).

3.14 Sulphate

Sulphate was found in very low concentration in Chini Lake with the mean value of 0.499±0.507 mg l^{-1} (ranges from 0.0 to 9.0 mg l^{-1}). The significant presence of sulphate in the lake (>1 mg l^{-1}) was observed at station 9 during March 2005 to May 2005 (Tables I and II). This phenomenon was highly related to the reactives of iron-mining activities near the station. However, stations located far away from station 11 and 12 remain unaffected.

4 Discussion

According to The Malaysian Water Quality Index (DOE-WQI), Chini Lake's water is classified as class II with a mean of 87.41±3.34, which ranges from 65.14 (class III) to 95.4 (class I) (Table III). This is suitable for recreational activities where body contact is allowed (DOE, 2002). A comparison with Malaysian Interim Water Quality Standard (INWQS) shows that the mean water temperature was within the normal range, for conductivity, nitrate, sulphate and TDS in class I, DO in class II (range from class I–IV), pH in class II (range from class I–III), turbidity in class II (range from class I–II), BOD in class II (range from class I–II), COD in class II (range from class I–II), TSS in class I (range from class I–II), and ammonia-N in class II (range from class I–II). No phosphate and chlorophyll-a standards were given in INWQS. Comparison with eutrophic status (UNECE, 1994) for the chlorophyll-a concentration indicated that the mean chlorophyll-a concentration in the lake (2.89 μg l^{-1}) was in mesotrophic condition i.e., >2.5 μg l^{-1} which ranges from oligotrophic (<2.5 μg l^{-1}) to eutrophic (>8 μg l^{-1}). The mean of transparency (not reported in the results) and phosphate readings of 1.2±0.5 m and 0.062±0.016 mg l^{-1}

respectively were also indicated mesotrophic condition of the lake. This results are comparable with the study conducted in Lake Bera, Pahang (largest natural lake in Peninsular Malaysia, located about 50 km from Lake Chini) which showed that the range of temperature was 23.7–31.2°C; dissolved oxygen, 1.36–4.00 mg l^{-1}; pH 4.45–6.83; conductivity, 10.5–23.0 μS/cm; water hardness, 1.04–3.88 mg l^{-1} $CaCO_3$; sulphate, 0.96–5.59 mg l^{-1}; phosphate, 0.00–0.105 mg l^{-1}; nitrate, 0.01–0.29 mg l^{-1} and ammonia-N, 0.00–0.767 mg l^{-1} (Ikusima, Lim, & Furtado, 1982).

In general, the water quality in Chini Lake varies with season (dry, normal or wet season) and the location of the sampling stations. During wet season, reverse flow of flooded water of Pahang River can contribute to high suspended solid (TSS and turbidity) and ammonia-N to the Chini Lake and the effect to the sampling stations will depend on the level of the flood in the lake. If the flood is low, only sampling stations near the Chini River will be affected such as station 4, 5, 6, 8 and 9 (Figure 1). Correlation analysis shows significant relationship between rainfall and ammonia-N ($r= 0.387$, $P<0.001$) and between ammonia-N and TSS ($r= 0.679$, $P<0.001$). In dry season, increase in chlorophyll-a concentration was found in most of the stations. Intensive heat from the sun and stagnant water movement due to lack of rain are believed to be the main factor of the algae bloom in August 2004. Bennion et al. (2005) found that lakes with a retention time >3 days were consider to be sensitive to nutrient enrichment. The chlorophyll-a concentration dropped dramatically to 0.97 μg l^{-1} in September 2004 as an increased in precipitation in that month (Table I). Correlation analysis shows that chlorophyll-a concentration formed a significant negative correlation with the rainfall ($r= -0.448$, $P<0.001$). High precipitation may lead to high flushing rates and reduce the availability of solar energy due to the extent of cloud cover (Le Gren & Lowe-McConnell, 1980). High turbidity of the lake water during flooded period can also cause unfavourable conditions for the growth of phytoplankton, decrease in amount of submerged macrophytes and density of attached algae and lower radiation levels (Dokulil, 1993; Ikusima et al., 1982). Phosphate concentrations were also found higher than the mean which is >0.04 mg l^{-1}. According to EPA (1976), phosphate concentration that exceeded 0.025 mg l^{-1} may stimulate excessive growth of algae and other aquatic plants which can be a nuisance.

Water quality in Chini Lake also varies with location of the station in the lake. In term of water quality index (WQI), station 13, 14 and 15 have the highest score of the WQI, which ranges from 85.14 to 95.4 (class I to II). Station 5 and 6 recorded the lowest WQI among the stations especially in the month of September to November 2004 (class III) i.e., in the raining season where the contribution of the TSS and ammonia-N were high from the reverse flow of the flood water of Pahang River. These stations were also recorded lowest DO compare to other stations in the lake due to the flooded water. Similar condition was observed in Lake Bera during the great floods in wet season (Ikusima et al., 1982). Station 1, 2 and 3 are more affected by the organic substance and some nutrient especially phosphate. These stations are near to the settlement of the indigenous people at Gumum area (Figure 1), a resort and a National Service Centre camp which could contribute the organic loading. Improper sanitation system in local villages, resort and camp might brought extra biological loadings into the lake, thus increase the BOD values. BOD reading and to some extent the COD were high at these stations as compared to other stations in Chini Lake with reading ranges from 0.3 to 5.29 mg l^{-1} for BOD and 9.9 to 24.95 mg l^{-1} for COD. Phosphate reading was also high (up to 0.357 mg l^{-1}) especially at station 1. The main source of orthophosphate into Chini Lake was the daily activities of the local community in the lake such as human excretion and the use of detergents. Detergent polyphosphates produces orthophosphate by hydrolysis in natural water (Allen & Kramer, 1972; Golterman, 1975) and is the only directly utilizable form of soluble inorganic phosphorus (Wetzel, 1983). Sulphate readings were also found high at station 11 and 12 and also to some extent at station 10. Conductivity readings were also high at these stations. This phenomenon was highly related to the reactivation of iron-mining activities near station 11. Some effluents from the mining area were believed has been discharge into the lake and also through seepage. The primary source of sulphate can come from the precipitation of sulfur compounds that originated by combustion of fuel and also from the mining area (Wetzel, 1983). In term of pH value, station 5 and 15 show significant different (ANOVA $P<0.001$, Tukey–Kramer, $P<0.05$) from other stations. The acidity of natural lake ecosystems are found to ranged from 4.5–

6.5 (Chapman, 1992). Low pH values are found in natural waters rich in organic matter (Wetzel, 1983) and this can be seen especially at station 15 where there are abundant decaying aquatic weeds (C*abomba furcata*) which can result in low pH values as decomposition activities occurred.

5 Conclusions

Chini Lake is a shallow and small natural lake, which is a sensitive ecosystem and responded to the changes, episodes from its surroundings. Water quality in Chini Lake varies with season and the location of the sampling stations. High precipitation during wet season can generate changes to the lake water quality through reverse flow of flood water from Pahang and Chini River. High concentration of TSS, TDS, conductivity, turbidity and ammonia-N were found in raining season and stations closed to the Chini River are the most affected (Tanjung Jerangking area). These stations were also have low DO. Because of the barrage built at the end of Chini River, the flow back of the water to Pahang River is slow and most of the sediments are trapped in the lake and Chini River. In dry season, low volume and stagnant water could created eutrophic condition in the lake. The revival of abandoned mines had contributed to increase conductivity and sulphate concentration in the water. Stations located in Gumum area were also polluted by organic substance and nutrient. Overall, water quality in Chini Lake is classified as class II. WQI also varies with location of the station in the lake. Station 13, 14 and 15 have the highest score of the WQI (class I to II), while station 5 and 6 showed the lowest WQI (class III). The rapid expanding of agriculture land used was a major threat to the lake water quality as some plantation areas (oil palm) are close to the edge of the lake water body. Lake resource management should be given a serious consideration as it is a natural lake and plays an important role in the maintaining of a stable ecosystem. In order to protect and preserve Chini Lake as a national heritage, long term strategies need to be formulated. This includes development of monitoring and assessment strategies to safeguard the healthy environment of the lake for the future generations.

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