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# The assessment of sedimentation and water quality status for river catchment management in Kenyir Lake Basin

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**ABSTRACT**

Kenyir Lake Basin was built to generate hydroelectric power for Peninsular Malaysia. This water body is a promising natural preserved environment and has been attracting the developer to develop tourist spots to fulfill their profit margin. Such approach commonly has been polluting the environment since the past few decades. In the present study, the hydrological and water quality assessment on rivers was carried out to identify the existing physical environment of Kenyir Lake Basin. Samples and in-situ data were collected at 19 stations during the dry and wet season. The obtained data was compared with National Water Quality Standard (NWQS) for Malaysian waters as well as interpreted and analysis using chemometrics technique. Based on the climatology and hydrological data, it has been observed that the sedimentation rate is increasing which may damage the Kenyir Dam turbines in the future. Besides that, the water quality of Kenyir Lake Basin is complied to Class IIB NWQS which is suitable for recreational use with body contact. Similarly, Kenyir Lake Basin is classified as Class III based on Malaysian Department of Environment (DOE) water quality index; which is suitable for body contact recreational activities but requires an extensive treatment. The chemometrics analysis has highlighted total dissolved solid, turbidity (TUR), biological oxygen demand, chemical oxygen demand and salinity have affecting the water quality. Additionally, dissolved oxygen and pH showed higher potential risk toward the environmental process management and monitoring owing to the development surround Kenyir catchment area. The present findings advocate a higher management method to facilitate the preservation and maintain the life of Kenyir Lake Basin.

*Keywords:* Kenyir Lake; Sedimentation; Water quality; Chemometrics; Preservation

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## 1. Introduction

Rivers, streams and lakes can be subjected to regulation by well-established practices through the use of dams, storage reservoirs and diversions. The role of lakes in the hydrological system depends on their very existence upon a balance between their sources of water and the losses that they experienced. However, the increasing of human activities has led the wildlife habitats to change, shrink and breakdown to the extent that they may no longer be self-sustain. Additionally, such drastic development is commonly causing a serious sedimentation problem which will contribute to a large amount of pollutants and deteriorate the quality of the lake water [1–5].

In Malaysia, the environmental annual report issued by the Department of Environment (DOE) has defined two main anthropogenic factors that cause river pollution is the land use development and urbanization. The quality of water is sensitive to the environmental changes which initiate the restriction on water utilization in order to enhance the water quality management program [6,7]. Due to the needs for an environmental management, Department of Environment (DOE) has created a guideline named by National Water Quality Standard (NWQS); with the purpose of classifying the freshwater quality based on their beneficial uses [8,9]. According to NWQS, only six significant water quality parameters were selected, namely the dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen ($NH_3$–N), total suspended solid (TSS) and pH (Table 1) [10].

Other than that, the sedimentation is another concern in the management of water resources of the lake. It can reduce the capacity of lake as the lake floor becomes shallower. Sediment can be defined as the organic and inorganic materials which is transported from one place to another place through the erosion process and deposited in a new location. Sedimentation is influenced by the processes of erosion, transport and deposition along the river towards the estuary. The degree of sedimentation can be estimated by using TSS and river discharge [11–13]. The main purpose of the present study is to identify the existing physical environment of Kenyir Lake Basin through the hydrological and water quality assessment. Both studies aspects will be beneficial to Kenyir Lake Basin and its catchment in order to have a better and environmental management program. Fig. 1 shows the land use distribution of Kenyir Lake Basin, during the year of 2010 to 2020 [14]. In general, the Kenyir Lake land used is dominated by business, recreational, institution, transportation, empty land, agriculture, forest or National Park Resort and water body. Approximately 50% of Hulu Terengganu is covered with forest area including the National Park Area. Apart from that, the other areas are predominating by the forest production areas. The distribution of land status of Hulu Terengganu is owned by the state government whereas few other areas are private owned land. Based on the Rancangan Tempatan Daerah (RTD) Hulu Terengganu comprehensive plan, the future land use status will establish a range of densities (amount of residential development per acre) and intensities (amount of non-residential development per acre) on a specific site. Additionally, the estimated land used of Hulu Terengganu for forest area has decreased from 2010 to 2020 [14].

In recent years, attention has been given to how land use changes may affect the hydrological response [15–17]. The increases in population, as well as urbanization, may contribute to development (residential and industrial areas) in the floodplain. The land use change due to human activities may influence the hydrological processes through evapotranspiration and infiltration. Deforestation may increase in overland and river flow due to the lower evapotranspiration capacity. In contrast, urbanization may lead to a greater impervious surface area. The land use change analysis has suggested that the upstream area experienced the most land use change. According to the land use status planning for year 2020, 7.04% of Hulu Terengganu areas will build with new dam. Kenyir Lake will be expanded as Hulu terengganu hydroelectric which will cover Tembat River and Puah River. This project comprises of the development of two dams crossing Puah River and Tembat River namely the Puah Dam and Tembat Dam respectively. Water from both dams will inflow towards Kenyir Lake. Due to the development plan, a large area of the forest land used will then developed into mix-agriculture in the upstream area as well as the land development. The reported land used data by RTD Hulu Terengganu for 2010 found that this area was dominated by forest (221,836.75 hectares), water body (41,783.99 hectares), agriculture (43.65 hectares), construction (102.48 hectares) and empty land (252.3 hectares). In the meantime, based

Table 1
National Water Quality Standard (NWQS) for Malaysian freshwater

| Parameter | Class | | | | | |
|---|---|---|---|---|---|---|
| | Unit | I | II | III | IV | V |
| pH | – | >7 | 6–7 | 5–6 | <5 | >5 |
| DO | mg/L | >7 | 5–7 | 3–5 | 1–3 | <1 |
| BOD | mg/L | <1 | 1–3 | 3–6 | 6–12 | >12 |
| COD | mg/L | <10 | 10–25 | 25–50 | 50–100 | >100 |
| TSS | mg/L | <25 | 25–30 | 50–150 | 150–300 | >300 |
| AN | mg/L | <0.1 | 0.1–0.3 | 0.3–0.9 | 0.9–2.7 | >2.7 |
| Water quality index (WQI) | | <92.7 | 76.5–92.7 | 51.9–76.5 | 31.0–51.9 | >31.0 |

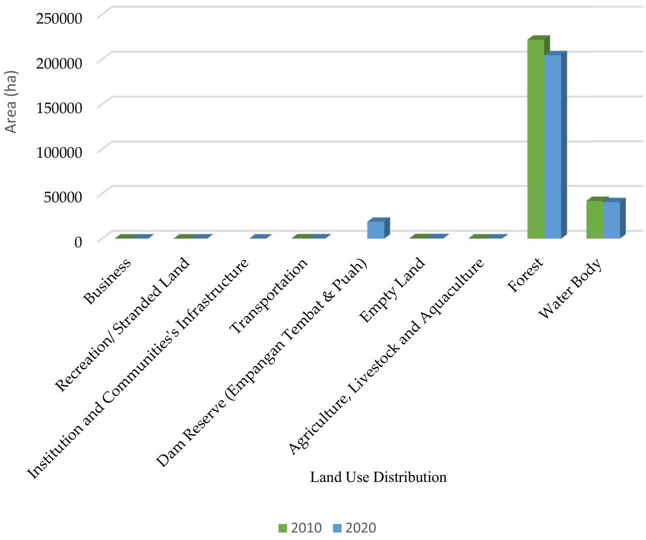


Fig. 1. Land use distribution of Kenyir Lake of 2010 to 2020.

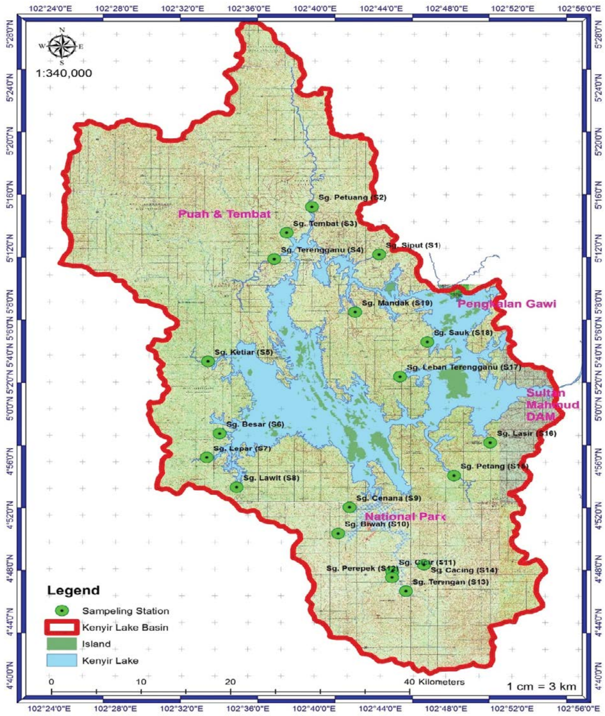


Fig. 2. The sampling station (selected 19 sampling stations).

on the RTD Hulu Terengganu future land used during the period of 2010 to 2020 has estimated approximately 204,604.56 hectares of forest and 40,623.76 hectares of water body area. The estimation has emphasized the decreasing of forest land used area from 2010 towards 2020 [14].

## 2. Study area and research methodology

### 2.1. Study area

Kenyir Lake Basin is the biggest man-made lake in the Southeast Asia. The water catchments extent over an area of 260,000 ha with 90% natural environment and covered by more than 340 islands. The lake has an average depth of 37 m with a maximum depth of 145 m. Additionally, Kenyir Lake Basin has more than 14 waterfalls and numerous rapids and rivers. Kenyir Lake Basin is a one of the famous lake in Terengganu, Peninsular Malaysia which offers a fascinating tourist spot such as waterfalls, limestone caves and lush tropical forest. Besides that, the surrounding area has accommodated more than 8,000 species of flowers, 2,500 species of plants and trees as well as 300 species of fungus. This water body lies at latitude 05°11′01.064′′N until 05°07′34.463′′N and longitude 102°42′42.602′′E until 102°20′6.25′′E and has been received water input from Terengganu River [14]. This water catchment was built with the purpose of generating hydroelectric power to supply electricity to all states in Peninsular Malaysia. Kenyir Dam was constructed since 1978 to 1985 [18–20]. The present study has selected 19 sampling stations which cover natural rivers, cascades and waterfalls (Fig. 2).

### 2.2. Research methodology

Sample preparation and preservations were carried out according to American Public Health Association (APHA) and United States Environmental Protection Agency (USEPA) methods. The in-situ parameters were measured using calibrated scientific equipment's. DO, pH and $NH_3$–N were measured using portable multiparameter probe, YSI Professional Plus; whereas BOD concentration was measured by using portable BOD meter, Modern Water BOD Chek. In the meantime, water samples were collected for COD and TSS. Water samples for COD were preserved, kept at low temperature prior transportation to the laboratory and analyzed using DR 2800 Portable Spectrophotometer. Overall, the laboratory analysis was completed within 14 d from the date of sample collection. In the meantime, water samples for TSS were treated according to Gravimetric method. Samples were filtered using 0.45 µm membrane filters, dried and weighted. TSS was measured by mg/L unit and calculated using Eq. (1). Precisely, the interference of the river water flow should be minimized in order to avoid deposition of the measured suspended sediment [21,22].

$$\frac{\text{TSS (mg/L)} = (\text{WMAF} - \text{WMBF})\ \text{mg}}{\text{Volume of filtered water (mL)}} \times 100 \tag{1}$$

where WMAF = Weight of membrane filter after filtration; WMBF = Weight of membrane filter before filtration.

The capacity of sediment transportation and movement is mainly influenced by the flow of water velocity. Furthermore, the process of deposition of sediment depends on the river discharge level ($Q$) and the speed of the river flow ($V$) [23,24]. Basically, the downstream areas have higher discharge value and water velocity compared to the upstream areas [25,26]. This could trigger the higher amount of sediment load deposited. In the present study, the velocity of stream flow was measured using a portable current meter portable, the Rangefinder (Model Bushnell 20-0001) was used to measure the river width (distance between the river banks) as well as and the depth meter was used to measure the depth of Kenyir Lake. The discharge value ($Q$) is the product of velocity and cross-section area ($A$). The cross-section area is derived from the product of depth ($D$) and width ($L$). It is well known that the cross-section area is normally in trapezium or triangular shape. Therefore the value is half the product as shown in Eqs. (2) and (3). Fig. 3 shows the illustration of theoretical of discharge ($Q$) measurement based on the cross-section of the river [16]).

Discharge value ($Q$):

$Q$ = vA, or $Q$ = ½ vA

$Q = m^3/s$

A1 = 1/2 (L1 × D1)

A2 = L2 [(D1 + D2)/2]

A3 = L3 [(D2 + D3)/2]

A4 = 1/2 (L4 × D3)

$A$ = dw (m) or A = ½ dw (m)

$\sum$ A1 + A2 + A3 + A4 (2)

To obtain the discharge value based on unit L/d, the following formula is used:

$$Q = m^3\,s^{-1} \times 86{,}400\ s\ d^{-1} \times 1{,}000\ L\ m^{-3} = L\ d^{-1} \quad (3)$$

The statistical analysis methods applied were the hierarchial agglomerative cluster analysis (HACA), discriminant analysis (DA), principal component analysis (PCA) and statistical process control (SPC). CA was employed to investigate the grouping of the sampling sites (spatial), whereas DA was applied to determine the variables that discriminate between two or more naturally occurring clusters. In the meantime, PCA was utilized to provide information on the most significant parameters due to spatial and temporal variations [27]. It also describes the whole data set by excluding the less significant parameters with a minimum loss of original information. All data analysis was carried out using XLStat2014 and SPC XL licensed software for Microsoft Excel [28,29].

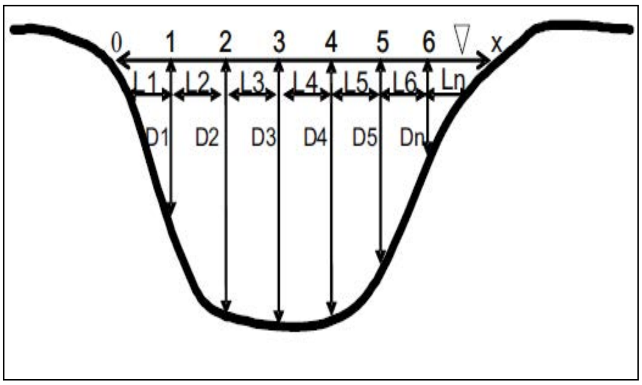


Fig. 3. The illustration of theoretical of discharge (Q) measurement by cross-section of the river.

## 3. Result and discussion

### 3.1. Climatology and hydrological status

There are three main sources of flooding namely heavy local rainfall, extreme river discharge and sea wave from South China Sea. Rainfall is one of the main water input to the river basin as it is strongly influenced the water storage and discharged of a river especially during heavy rainfall event. The generally seasonal variation of rainfall in Kenyir Lake Basin can be divided into two main types such as the rainfall intensity event occurs starting September to February (Northeast Monsoon Month as wet season) and the relatively dry event starting May to October which received relatively lower than the other months (normal season) [30,31]. According to the DID [32], there has been a big event occurred due to an intense rainfall during December 2014 [33–36]. This event has been affecting several areas such as Jerantut, Maran, Temerloh, Gua Musang and Nenggiri. Based on the developed isohyetal map the intensed rainfall was focused at the border of Terengganu and Kelantan with the range of 1,600 to 2,300 mm. During the same period, approximately 60 to 120 mm of cumulative rainfall has caused flood at National Park, Jerantut, Temerloh, Cameron Highland especially in Brinchang and Chini. The isohyetal map during January 2015 showed high intensity of rain was poured in Kuala Rompin with 700 mm to 800 mm rainfall. In the meantime, the rainfall intensity has dropped to a range of 40 to 120 mm (highlighted as blue color in Fig. 4) at the central area of Pahang state as well as the upstream area of Pahang River [32].

Generally, the temperature in Kenyir Lake Basin is range between 23°C to 31°C yearly. This rainfall catchment area is regularly received a yearly intense rainfall pour during the Northeast Monsoon season which is during the period of September to February. Therefore it is manifest that temperature within Kenyir Lake Basin area is lower than other area in Terengganu. The increasing of rainfall volume into water body may affect the chemical and biological activities in the lake water column. The database provided by Malaysian Meteorology Department (MMD) in Fig. 5a shows the distribution of mean monthly temperature in Kuala Terengganu from 2001 until 2017. The highest mean temperature was recorded in April, May and June every year and the lowest value was recorded during the wet season which is in the period of November to January [37]. As recorded by MMD, there is no significant change of relative humidity in Terengganu River basin throughout 2001 to 2017. The monthly mean relative humidity in Kuala Terengganu is 83%. There was a slightly seasonal change during March to October with relative humidity of 80% and 85%, respectively (Fig. 5b). In general, the relative humidity in Kuala Terengganu was slightly high. Relative humidity closed to 90% was possibly occurred in the morning and during the Northeast Monsoon season due to the increases of moisture supply rather than a reduction in temperature. The monthly

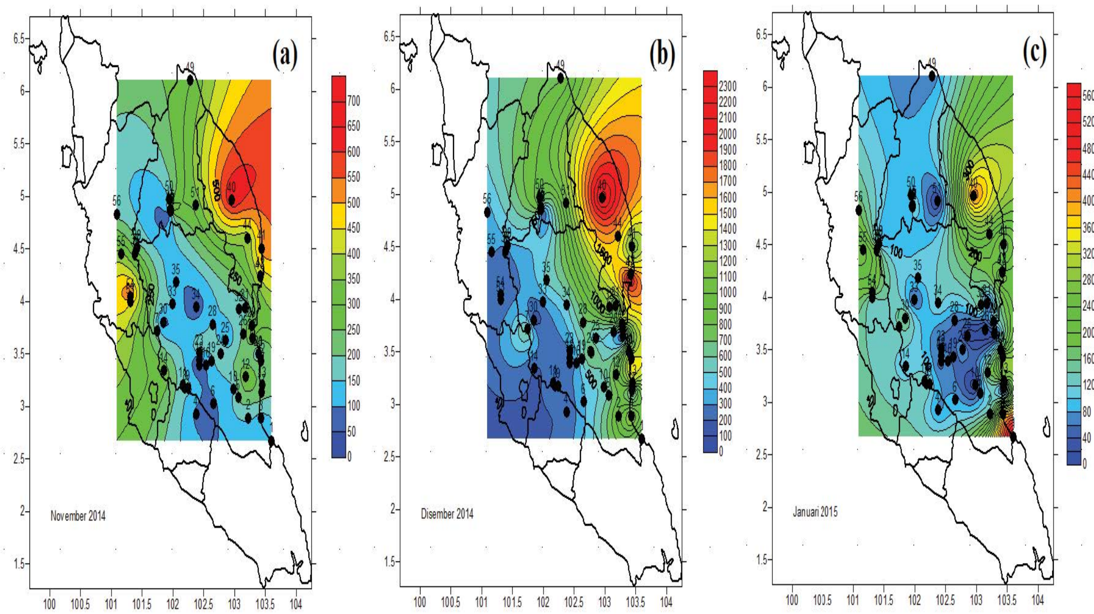


Fig. 4. The distribution of rainfall cumulative in Terengganu border during (a) November 2014, (b) December 2014 and (c) January 2015.

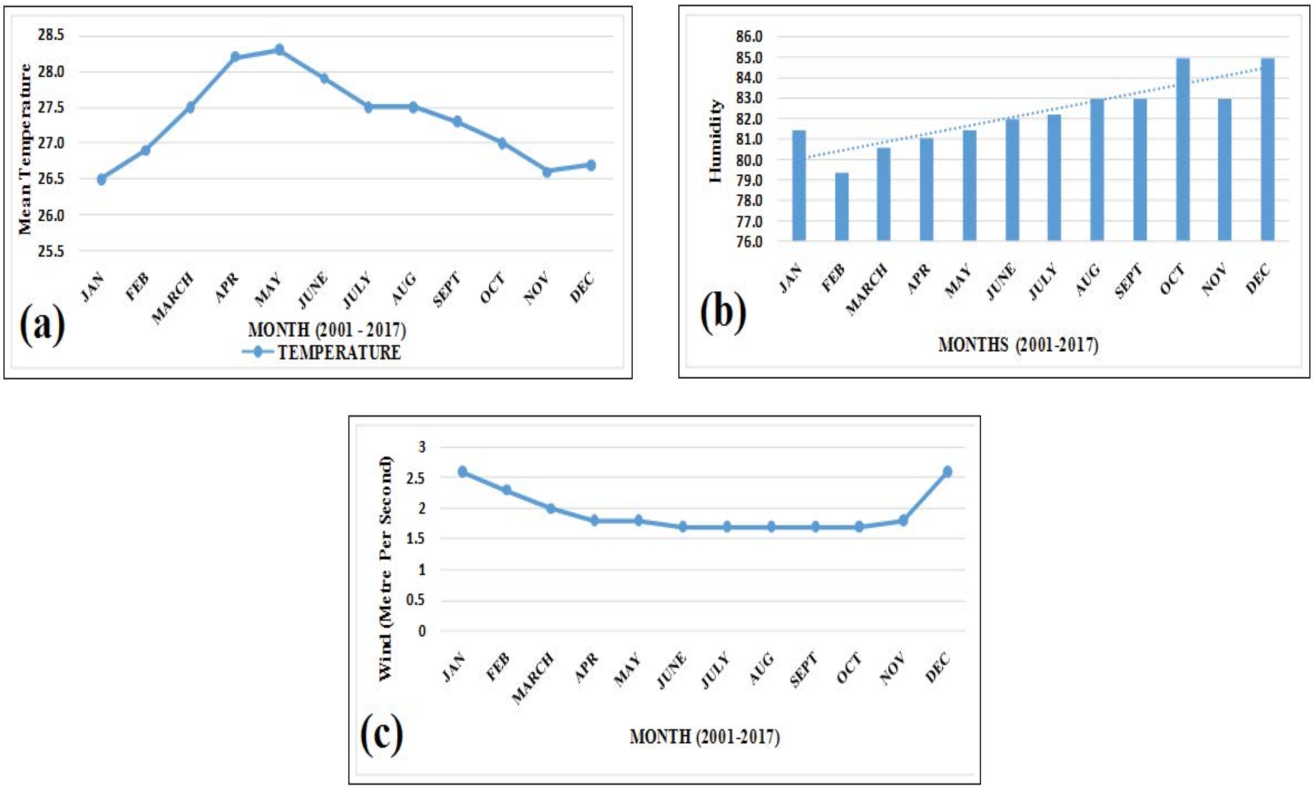


Fig. 5. The mean monthly temperature, humidity and wind recorded at Kuala Terengganu (48618) meteorological station (2001–2017).

wind speed recorded in Kuala Terengganu during 2001–2017 was quite variable (Fig. 5c) with the mean value of 1.9 m/s. However during November to January, the wind speed started to increase from 1.8 to 2.6 m/s. Next, the wind speed has decreased slowly to 2.3 m/s in February and become normal during April [38].

Fig. 6a shows the discharge data of the Berang River during the period of 1991 to 2006. Generally, these data were used to determine the amount and location of accumulated sediment since the Kenyir Dam was started. Ever since Kenyir Dam was operated, it is observed that there is an increasing of sedimentation rate in front of

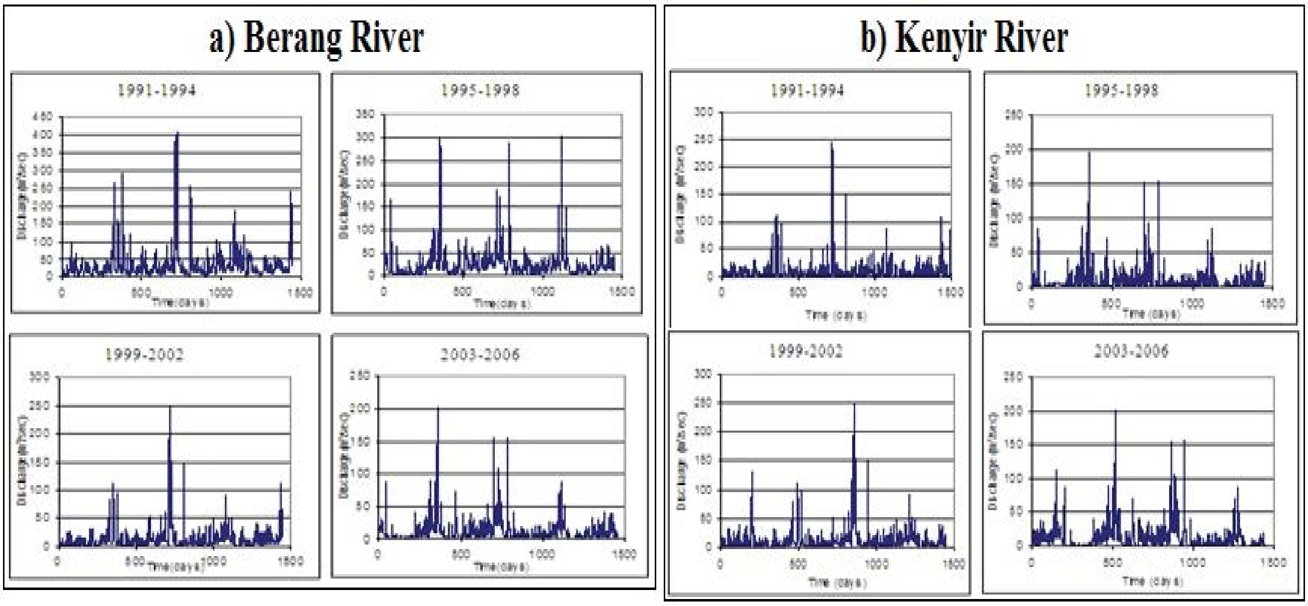


Fig. 6. (a, b) Discharged data of Berang River and Kenyir River for different periods.

the intake structure. It is visible during the extremely low water level. Additionally a murky water has been discharged from the turbines during the rainy seasons. Simultaneously, the inflow water from the Berang River and Kenyir River were observed to be high with sediment load (Fig. 6b).

Consecutively within few more years, more sediment will start to flow into the turbines which will cause damages and outages. Therefore it may call for a costly dredging. The observed discharged value at Station 2 shows the highest value of 10.48 m$^3$/s (Fig. 7). In the meantime, Station 10 shows the lowest discharged value with 0.07 m$^3$/s$^{-1}$. Generally, the excess water flows out of Kenyir Lake Basin into the Terengganu River. The difference in depth and width of the river will significantly influence the river water properties. Based on data collected in 19 selected tributaries rivers in the present study, it was estimated that more than 80% of the sediment production and water deterioration could be attributed to human activities. Besides that, the rate of soil erosion depends on the complex interaction of climate and catchment characteristics. In Peninsular Malaysia, despite of the high energy potential provided by tropical rain, the erodibility of soil cover and tropical rainforest of multi-layered canopy thick undergrowth have proven to be effective in limiting the soil erosion rate [23,39,40]. Theoretically, the river discharge is the primary factor which has influenced the sediment mobility and water quality of the water column. Since the intense occurrence of rainfall normally increasing the value of river discharge, therefore it will increase the concentration of suspended sediment. Then, sediment production in a basin has been greatly altered due to large-scale human perturbations along the basin (from upstream to downstream areas). Factors such as relief, channel slope, basin size, water flow, water level, river discharge, seasonality of rains and tectonic activities control sediment loads production in rivers [41,42].

### *3.2. Water quality status*

#### *3.2.1. Determination of lake water pollution risk according to INWQS Class IIB Standard*

All observed lake water quality for all sampling points in the Kenyir Lake Basin was compared to Class IIB National Water Quality Standard of Malaysia (NWQS) which is suitable for recreational use with body contact [43–46]. Fig. 8 shows that 100% of the observed data were complied with Class IIB of NWQS.

#### *3.2.2. Spatial classification of lake water quality pattern*

The HACA dendogram shows three different spatially patterns of the water quality sampled in the Kenyir Lake. Cluster 1 consists of 11 sampling sites; Cluster 2 consists of six sites; and Cluster 3 consists of two sites (Fig. 9). The three spatial water quality patterns were determined due to the different level of the water quality namely contaminated area (ConA), moderate contaminated area (MConA), and less contaminated area (LConA) as shown in Fig. 10. For future sampling plan, it is considered sufficient with at least three sampling points representing the three different clusters within the Kenyir Lake Basin.

#### *3.2.3. Spatial variation of lake water quality*

In order to study the spatial variation among the different sampling sites, DA was applied to the raw data which was clustered into three (3) groups of Kenyir Lake water quality. The DA results has confirmed that the status of current water quality at Kenyir Lake can be divided into three water quality patterns. The pattern which was recognized as "CA" is considered as high potential risk, "MCA" is considered as medium potential risk and "LCA" is considered as low potential risk due to area which receiving

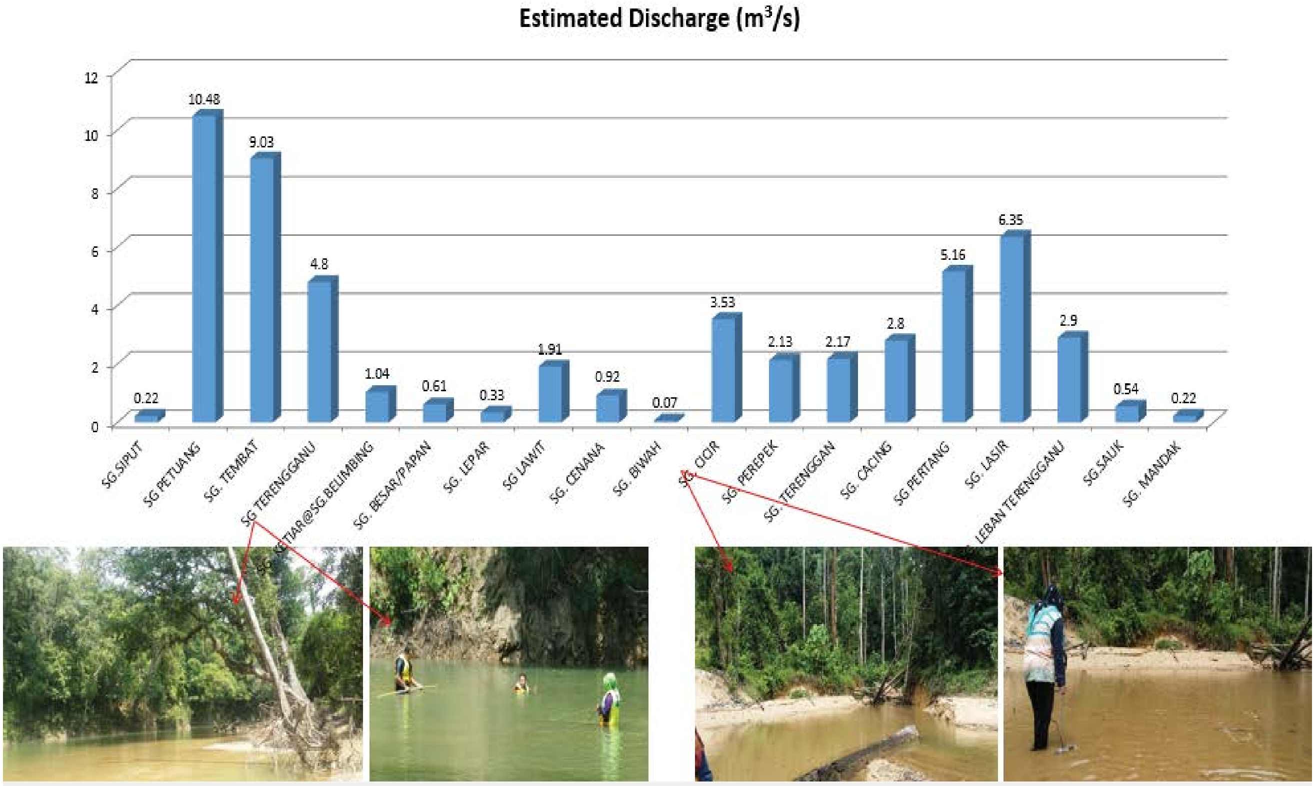


Fig. 7. Estimated river discharge for all sampling stations in Kenyir Lake.

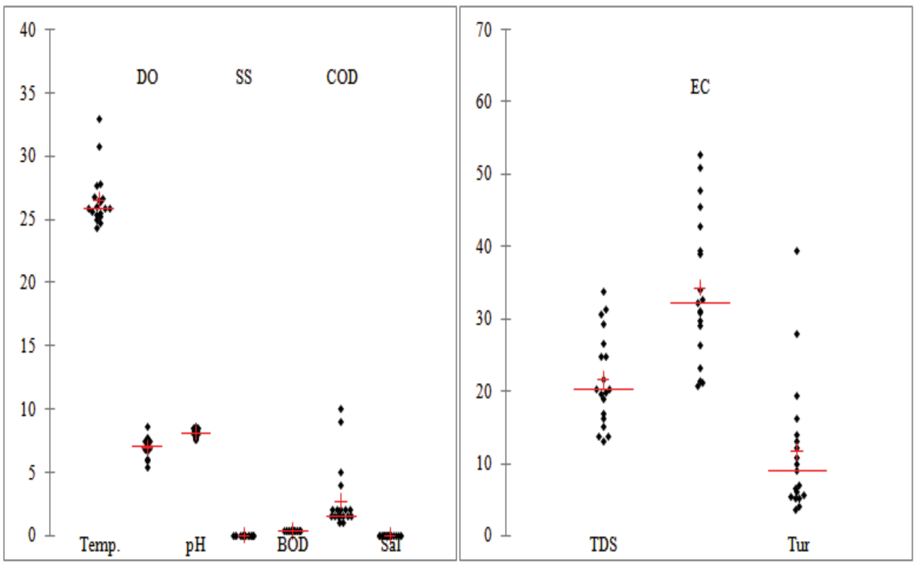


Fig. 8. The scattergrams of the observed lake water quality parameters distribution.

pollutants from the land-use activities surround the lake. All discriminant function analysis (DFA) was 100% correct classified with five discriminant variables, namely total dissolved solid (TDS), TUR, BOD and COD (Fig. 11). The spatial variation of TDS, TUR, BOD, COD and Sal is further illustrated in Fig. 12 by box and whisker plots.

*3.2.4. Process capability analyses for Kenyir Lake water quality*

In general, the lake water quality proved that Kenyir Lake water system is maintaining a good quality of water which complies with NWQS Class IIB via natural

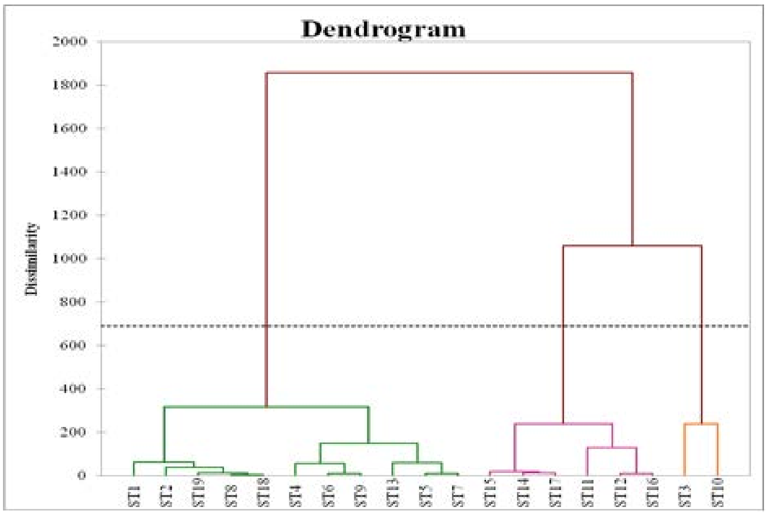


Fig. 9. Spatial classification of water quality based on different sampling location.

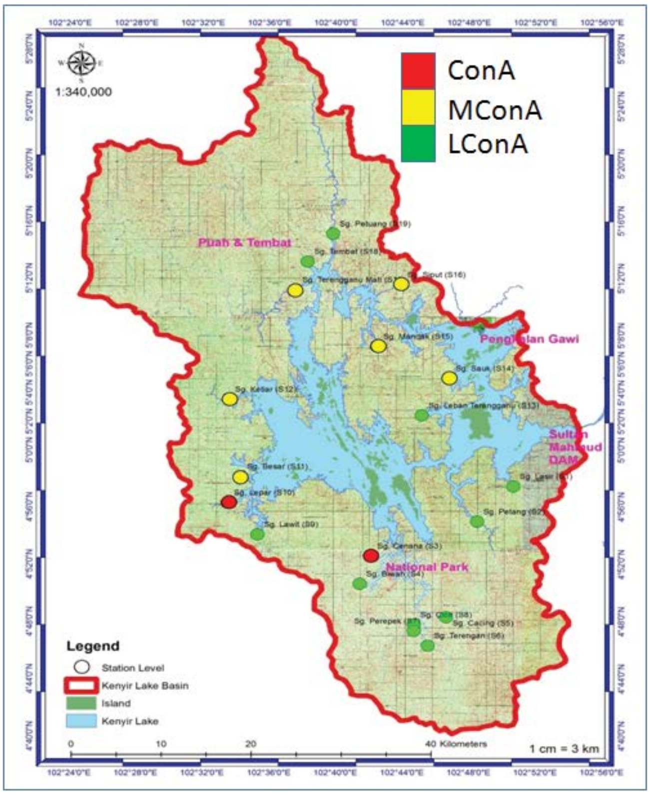


Fig. 10. Spatial pattern of Kenyir Lake Basin water quality.

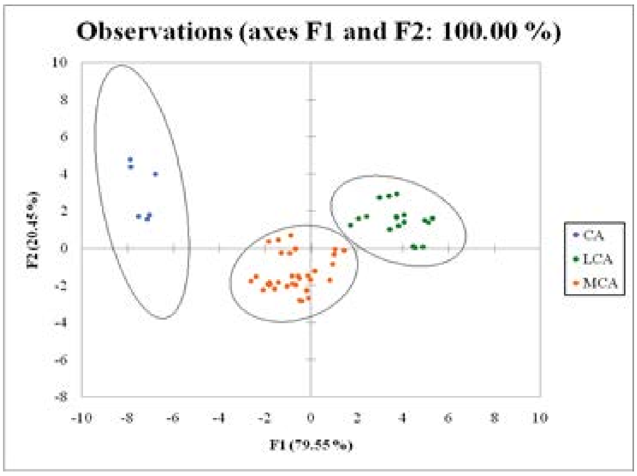


Fig. 11. Plot of discriminant functions for spatial variation of lake water quality.

self-purification in receiving the current pollution loading (Table 2). However, two parameters showed that the process is not stable where the capability index value is below and closer to one. This indicates that the process for both parameters is in bad performance.

*3.2.5. Water quality index*

Based on the Department of Environment-water quality index (DOE-WQI) calculation (Fig. 13), Kenyir Lake water column (upstream until downstream) was classified as Class III (72.76 ± 75.51) which require an extensive treatment for water supply. However, all stations showed WQI level above than 70% which is suitable for recreational activities and body contact. Therefore, a conservation program is needed through the lake management in order to control the pollution issue [15–18]. The comparison between the actual WQI and predicted WQI for Kenyir Lake during the present study proved that there are higher predicted values of WQI at downstream and middle stream compared to the actual level of WQI (Fig. 13). The main sources of pollutants were possibly derived from waste product and effluent originated from the urban development and activities along Kenyir Lake Basin. Based on the NWQS theory, most of the measured parameters remained in Class I from the upstream towards the downstream stations. Various anthropogenic activities along the stream are possible causing the significant changes in the water quality of the basin [47–52].

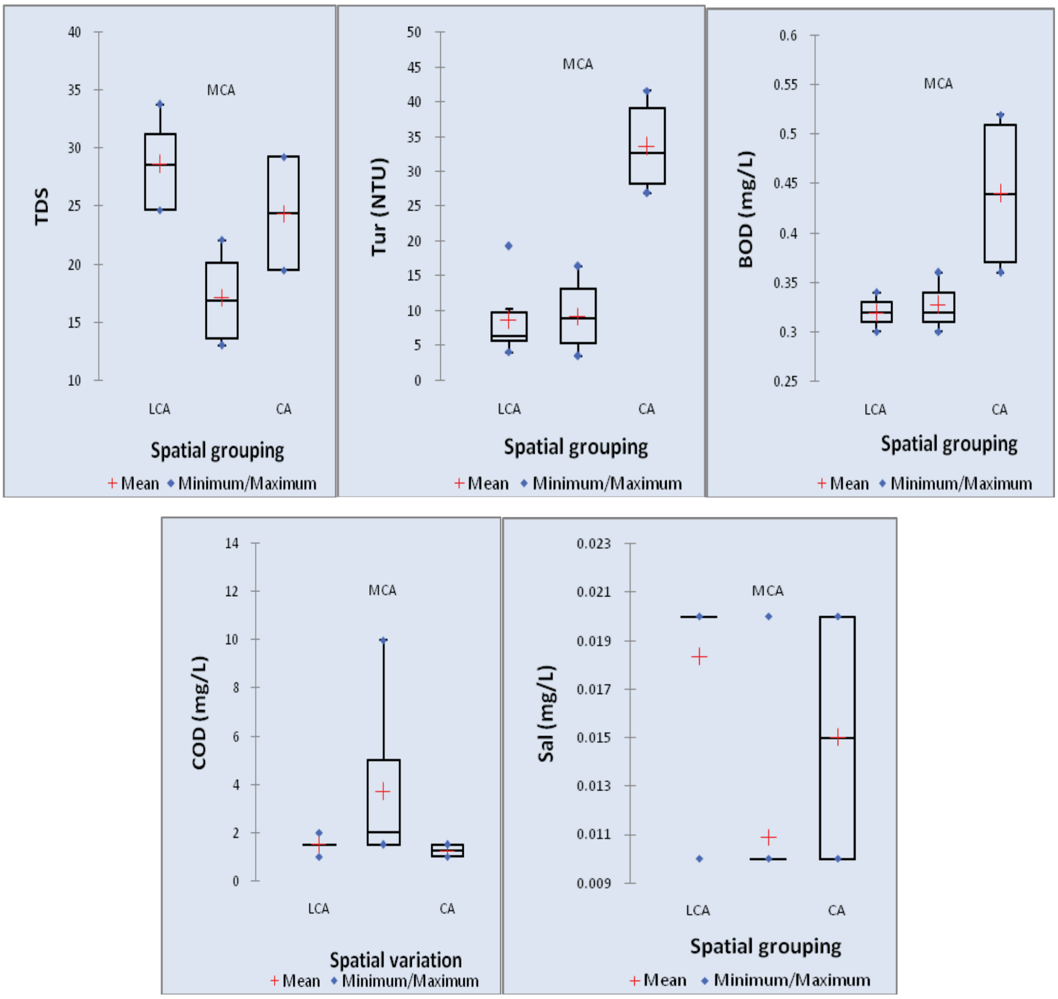


Fig. 12. Box and whisker plots of some parameters separated by spatial DA associated with water quality data of Kenyir Lake.

Table 2
Individual chart and moving range chart for water variable in Kenyir Lake

| Variable | LSL | CL | USL | Cpk-LT | Cpk-ST | Lake system process performance |
|---|---|---|---|---|---|---|
| DO | 5 | 6.99 | – | 0.92 | 1.01 | Bad |
| pH | 6.5 | 8.07 | 9.0 | 0.95 | 0.91 | Bad |
| TUR | – | 8.99 | 50 | 0.42 | 3.37 | Good |
| BOD | – | 0.33 | 3 | 2.45 | 6.45 | Excellent |
| COD | – | 1.60 | 25 | 1.58 | 2.41 | Good |
| Temp. | 23 | 25.93 | 34 | 1.04 | 1.53 | Good |
| TDS | – | 21.54 | 1000 | 1.12 | 1.63 | Good |
| EC | | 34.20 | 1000 | 1.13 | 1.72 | Good |

The leave-one-out method or input importance of water quality parameters variables analyses were carried out to determine the significant water quality parameters based on the WQI and hydrodynamic features. A linear relationship analysis has showed that pH gave the highest percent contribution (64.75%) towards the water quality level compared to other variables (Table 3). In the present study, Kenyir Lake water pH was controlled by COD which is normally form as carbonic acid in the water. Water pH showed an increasing value during the dry season. Generally natural water pH range between 6.0 and 8.5. However, the diluted water column may evidence a low pH due to high run-off organic content from the land [53–55].

Based on Table 3, DO have contributed 17.65% towards Kenyir Lake water quality throughout the present study. The highest concentration of DO in river water mainly

Table 3
Input importance of water quality parameters variables in linear relationship to the predict WQI in Kenyir Lake

| *R*-square reference = 0.99911 | | | |
|---|---|---|---|
| Leave variable | *R*-square leave variable | *R*-square difference | Percent contribution |
| DO | 0.99782 | 0.00129 | 17.65 |
| BOD | 0.99822 | 0.00089 | 12.18 |
| COD | 0.99902 | 9E-05 | 1.23 |
| TSS | 0.99879 | 0.00032 | 4.38 |
| pH | 0.99439 | 0.00472 | 64.57 |
| $NH_3$–N | 0.99911 | 0 | 0.00 |
| Total | 5.98735 | 0.00731 | 100 |

Table 4
Pearson correlation matrix between water quality parameters and WQI in Kenyir Lake Basin

| Variables | DO | COD | BOD | TSS | pH | WQI |
|---|---|---|---|---|---|---|
| DO | 1 | 0.191 | 0.006 | 0.334 | –0.452 | 0.086 |
| COD | 0.191 | 1 | –0.104 | –0.177 | –0.030 | –0.358 |
| BOD | 0.006 | –0.104 | 1 | 0.342 | 0.182 | –0.302 |
| TSS | 0.334 | –0.177 | 0.342 | 1 | 0.241 | –0.566 |
| pH | –0.452 | –0.030 | 0.182 | 0.241 | 1 | –0.792 |
| WQI | 0.086 | –0.358 | –0.302 | –0.566 | –0.792 | 1 |

Table 5
Correlation matrix (Pearson) between water quality parameters and river discharged (*Q*) in Kenyir Lake Basin, Hulu Terengganu, Terengganu, Malaysia, 2017

| Variables | DO | COD | BOD | TSS | pH | Discharge (*Q*) |
|---|---|---|---|---|---|---|
| DO | 1 | 0.191 | 0.006 | 0.334 | –0.452 | 0.389 |
| COD | 0.191 | 1 | –0.104 | –0.177 | –0.030 | 0.229 |
| BOD | 0.006 | –0.104 | 1 | 0.342 | 0.182 | –0.215 |
| TSS | 0.334 | –0.177 | 0.342 | 1 | 0.241 | 0.036 |
| pH | –0.452 | –0.030 | 0.182 | 0.241 | 1 | –0.266 |
| River discharge (*Q*) | 0.389 | 0.229 | –0.215 | 0.036 | –0.266 | 1 |

Values in bold are different from 0 with a significance level alpha = 0.05.

depends on the velocity of water, as well as the rainfall intensity. Therefore, the amount of DO in river is truly depends on the river discharge and its velocity. DO concentration is a fundamental part of a water quality assessment since oxygen is involved in chemical and biological processes within the water bodies (Zin et al. [59] and Rwoo et al. [60]). Table 4 shows that the TSS and pH value in Kenyir Lake was negatively correlated to WQI ($R$ = –0.566 and $R$ = –0.792). These results indicated that the main contributing factors of TSS and pH towards water deterioration along Kenyir Lake were caused by the release of contaminants from anthropogenic activities, waste treatment operations and abundant decaying aquatic weeds. These pollutants may lower the pH values as a result of decomposition of organic matter.

In the meantime, Table 5 shows the correlation of water quality parameters and WQI. This correlation shows a weak correlation between water discharged and water quality parameters namely DO, BOD, COD, TSS, pH and $NH_3$–N. Based on the hydrological theory, the increasing of water discharged will increase the TSS. However, the present study proved that the water discharged was not the main factor to increase the concentration of TSS and others parameters. Therefore, the Kenyir Lake water quality deterioration during the present study period did not largely depends on the water discharged but also depends on the others geomorphology factors especially the climate factors [56–60].

## 4. Conclusion

In general, Kenyir Lake is affected by the Northeast monsoon (wet season) yearly during the period of November to February. During this period, Kenyir Lake Basin is

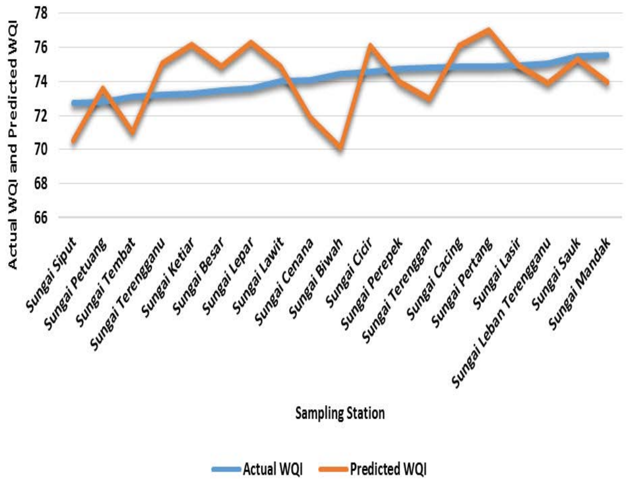


Fig. 13. Actual and predicted water quality index of Kenyir Lake, Malaysia.

experiencing an intense rainfall, low temperature, high relative humidity as well as strong wind. Since the present study was carried out during the dry season, the recorded data showed a contrast climatology status as compared to the wet season.

Based on the field observation during the low tide and collected data during the sampling activity, Berang River and Kenyir River were observed with high sediment load which evidence the increasing of sedimentation rate in front of the Kenyir Dam intake structure. This occurrence turns a call for an effective solution since within few more years; the increasing of sedimentation might damage the Kenyir Dam turbines.

The water quality data during the sampling period is complies with Class IIB of NWQS which is suitable for recreational use with body contact. In the meantime, spatial classification using CA shows that the water quality of all sampling stations was grouped as less contaminated area, moderate contaminated area and contaminated area. Other than that, DA has highlighted water quality variables which have been polluting the sampling stations namely TDS, turbidity, BOD, COD and salinity. Those parameters are the common variables which are closely related to sedimentation in the water column. According to the process capability analysis, the $C_{pk}$ index for DO and pH showed higher potential risk toward the environmental process management and monitoring due to the current development surround Kenyir Lake.

As for WQI classification by DOE has classified the sampling stations in Kenyir catchment area as Class III which is suitable for recreational activities and body contact but still an extensive treatment is required. The possible pollutant sources are the waste product and effluent from surrounded development, activities along Kenyir Lake as well as end product of decaying of the aquatic weeds. Based on the findings throughout the present study, it is strongly suggested for the need of a better management approach in order to conserve and maintain the nature of Kenyir Lake.

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