Research Article

# Evaluation of Eutrophication State of Mae Kuang Reservoir, Chiang Mai, Thailand by Using Carlson's Trophic State Index

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**Abstract**
Eutrophication is an event that occurred when the lakes have a high growth rate of phytoplankton and causing deterioration of water quality. In this work, we use Carlson's Trophic State Index (CTSI) to evaluate the situation of eutrophication of Mae Kuang Reservoir for the first time. Three parameters, i.e., total phosphorus, chlorophyll-a, and water transparency were used to calculate CTSI. The results showed that the reservoir has started to be eutrophic. In June and October, the ranges of the CTSI were 49.26–59.60 and 49.07–56.04, respectively, which indicated a low eutrophic state of the reservoir. However, in this primary eutrophic condition, the water quality was not bad, and the living organisms can survive. The CTSI is a valuable and simple alternative method for monitoring and estimating lake ecosystems' eutrophic status.

**Keywords**: Carlson's Trophic State Index, Eutrophication, Phosphorus, Chlorophyll-a, Turbidity, Mae Kuang Reservoir, Thailand

## 1 Introduction

Eutrophication is a phenomenon that reduces water quality. It is a process that lakes are characterized by excessive algal growth causes the increased availability of limiting growth factors needed for photosynthesis, especially phosphorus [1], [2]. The algal bloom limits light penetrating to the deep water, which later causes such organisms to die, and bacterial degradation of their biomass results in oxygen consumption, thereby creating a state of hypoxia. This process results in oxygen depletion of the water body. Eutrophication occurs over hundred years as lakes age that it is filled in with sediments [3]. However, human activities have encouraged eutrophication by loading limiting nutrients such as nitrogen and phosphorus from wastewater, agriculture, and industry into an aquatic system. The process of eutrophication causes a high level of algae that reaches the depletion of oxygen levels. As the oxygen levels in the water decrease the living organisms, such as fish cannot survive [4]. Many researchers have studied water quality in lakes, dams or reservoirs and agreed that phosphorus is an important nutrient and potential pollutant for eutrophication. Phosphorus is the main nutrient affecting the growth of algae and increasing the chlorophyll-a.

The basic method that is the most commonly used method for evaluating trophic state is based on the productivity of the water body, which is the biomass-related trophic state index developed by Carlson [5]. Carlson's Trophic State Index (TSI) concept of trophic status is based on the fact that changes in nutrient levels cause changes in algal biomass, which in turn affecting water transparency. This method uses total phosphorus, chlorophyll-a, and Secchi's disc transparency measurements. The trophic state explained the total biomass in a water body at a specific location and time. The trophic state is related to the biological response to phosphorus addition to the water sources [6]. Phosphorus is usually considered as the "limiting nutrient" in aquatic ecosystems, meaning that the available quantity of this nutrient controls the algae and aquatic plants growths. In excess quantities, phosphorus can lead to eutrophication and harmful algal growth.

However, since phosphorus generally occurs in small quantities in the natural environment, even small increases can negatively affect water quality and biological condition. In water resources, soluble phosphorus or orthophosphate has many forms; thus, the total phosphorus in water is considered for evaluation. Chlorophyll-a is the pigment that makes plants and algae green. This pigment allows plants and algae to photosynthesize. Chlorophyll-a is an index to explain how many algae are in the water. If the algal concentration increases, the water transparency decreases. This means that less light can enter through the water, so the algae can live only at the very top surface of the lake where there is enough light for photosynthesis.

The trophic continuum is divided into units based on the base 2 logarithmic transformation of Secchi disc depth. Each 10 unit division of the index represents a halving or doubling of the Secchi disc depth. Because the total phosphorus frequently corresponds with the transparency, a doubling of total phosphorus often corresponds to a halving of Secchi disc depth, which chlorophyll-a doubles every seven units [5]. The range of the index is from 0 to 100. The index was developed to place these three characteristics on similar scales to allow comparisons among water bodies.

Oligotrophic (TSI values less than 40) is a state with a limited supply of phosphorus; water is clear with low phosphorus concentrations and low algal populations, and generally contains oxygen throughout the year in their deepest zones. Mesotrophic (TSI values between 40 and 50) is a state with a moderate supply of phosphorus, moderate clarity, and trend to moderate algal blooms; occasional oxygen depletion in the deepest zones is possible. Eutrophic (TSI values between 50 and 60) is a phosphorus-rich state that has a phosphorus-rich with severe water-quality problems, such as frequent seasonal algal blooms and poor clarity or oxygen depletion in the deeper zones. Hypereutrophic (TSI values higher than 60) is a higher state of eutrophic, and it has extramely high phosphorus contents and usually experiences extensive algal blooms.

Maryam *et al*. [7] presented the Carlson's TSI in the summer and winter seasons of Ekbatan Dam in Iran. They showed that in summer, the lake's trophic state is lower mesotrophic, and in water, it turms to be high mesotrophic. However, phosphorus is the limiting nutrient in this dam, and this reservoir may have a severe problem of eutrophication in the long term. Deepa *et al*. [8] investigated Carlson's TSI for five lakes in India in pre-monsoon and post-monsoon from December 2013 to May 2014 and concluded that all of the lakes are eutrophication. The activities from the surrounding residential areas, such as washing, bathing, and manure from the animals may input the nutrient, especially phosphorus, to the lakes and cause excess growth of phytoplankton. Based on these studies, Carlson's TSI is an easy method for recognizing the level of eutrophication.

Mae Kuang Udomtara or Mae Kuang Reservoir is an important reservoir in Chiang Mai province, especially for irrigation, water supply, and fishery. However, this reservoir has been had algal bloom toxic [9], and nowadays, the level of water in this reservoir is very low. Thus, in this work, the Carlson's TSI method was used to evaluating eutrophication state of this reservoir for the first time. This method has not been widely used in Thailand.

## 2 Materials and Methods

### 2.1 *Study site*

Mae Kuang Reservoir is located in Doi Saket District, Chiang Mai Province, at latitude 18°56'50" in the North and Longitude 99°7'69" in the East. The altitude is 350 m above sea level, and it has 569 km$^2$ catchment area, 11.8 km$^2$ surface of water area, and 40–45 m in depth. There are two main ways for water inflows, which are Huay Mae Kuang and Huay Mae Lai and two main canals for water outflow. The areas of first canal supplied water to Doi Saket and San Kam Phaeng District of Chiang Mai Province, and Ban Thi and Muang District of Lamphun province, are 141.904 km$^2$ in total. Another canal supplies water to agriculture farming in San Sai District of Chiang Mai Province

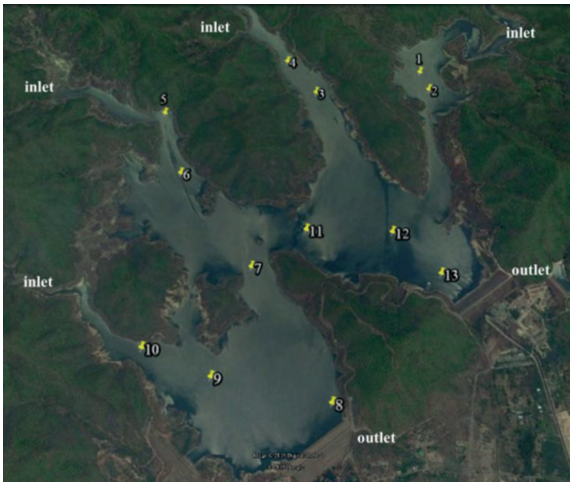


**Figure 1**: Satellite image of Mae Kuang Reservoir and localtion of 13 sampling sites.

in 18.496 km$^2$ area [10]. Thirteen sampling sites were selected for water sampling at the Mae Kuang Reservoir and they were located in different parts of the reservoir as indicated in the Table 1 that shows the geographical location of sampling points of Mae Kuang Reservoir; Figure 1 shows the location of sampling points from the satellite image, and Figure 2 is the map from GIS program.

**Table 1**: Geographical location of sampling points of Mae Kuang Reservoir

| Site | Latitude | Longitude |
|---|---|---|
| 1 | 18° 57′ 36′′ | 99° 8′ 7′′ |
| 2 | 18° 57′ 29′′ | 99° 8′ 10′′ |
| 3 | 18° 57′ 28′′ | 99° 7′ 32′′ |
| 4 | 18° 57′ 41′′ | 99° 7′ 22′′ |
| 5 | 18° 57′ 19′′ | 99° 6′ 42′′ |
| 6 | 18° 56′ 57′′ | 99° 6′ 46′′ |
| 7 | 18° 56′ 26′′ | 99° 7′ 12′′ |
| 8 | 18° 55′ 46′′ | 99° 7′ 34′′ |
| 9 | 18° 55′ 54′′ | 99° 7′ 1′′ |
| 10 | 18° 56′ 1′′ | 99° 6′ 42′′ |
| 11 | 18° 56′ 38′′ | 99° 7′ 28 ′′ |
| 12 | 18° 56′ 37′′ | 99° 7′ 54′′ |

Samplings of water were from the surface water of 13 sampling points using one liter of polyethylene bottle. Water samples were collected twice a months from June and October 2017.

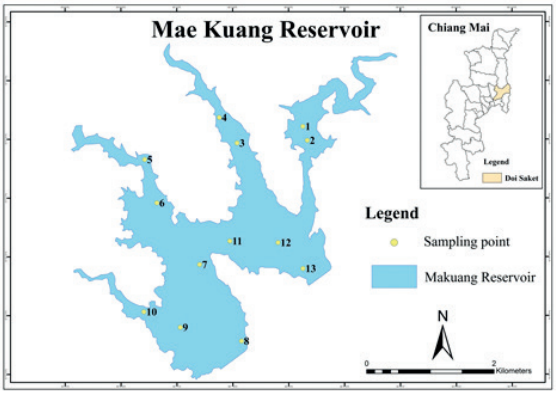


**Figure 2**: Mae Kuang Reservoir and 13 sampling sites.

## 2.2 *Carlson's trophic state index (CTSI)*

*2.2.1 Transparency*

Transparency of the water was measured by Secchi's disc of 20 cm in diameter, and the values are expressed in meters. The maximum depth as the Secchi's disc has been seen when the disc was dropped into the water is measured.

*2.2.2 Total phosphorus*

Total phosphorus was determined by using sulfuric – nitric digestion method and measuring phosphorus content by molybdenum blue method [11].

*2.2.3 chlorophyll-a*

The concentration of chlorophyll-a was estimated by the methanol extraction method [12] and measured using a spectrophotometer.

*2.2.4 Carlson's Trophic State Index formula*

TSI by Carlson was calculated by using the following formula [13]

*TSI for Secchi disk depth (TSISD)*

$$TSISD = 60 - [14.41 \times \text{Ln Secchi depth}]$$

*TSI for Total phosphorus (TSITP)*

$$TSITP = [14.42 \times \text{Ln Total phosphorous}] + 4.15$$

*TSI for Chlorophyll-a (TSICA)*

$$TSICA = [9.81 \times \text{Ln Chlorophyll-a}] + 30.6$$

Where TSI is Carlson's Trophic State Index, and Ln is natural logarithm. The unit of Chlorophyll-a and Total phosphorus is µg/L, and the unit of SD is m.

$$CTSI = [TSITP+TSICA+TSISD]/3$$

The values of TSI range from 0–100 are categorized as oligotrophic, mesotrophic, eutrophic and hypereutrophic. The description of Carlson's trophic state index values is displayed in Table 2.

**Table 2**: The description of Carlson's TSI values

| TSI | Trophic Status | Description |
|---|---|---|
| 0–40 | Oligotrophic | Clear water, low nutrient content |
| 40–50 | Mesotrophic | Water moderately clear, medium level of nutrient |
| 50–80 | Eutrophic | High algal blooms, high nutrient content, decreased oxygen |
| 80–100 | Hypereutrophic | Highest algal blooms, highest nutrient content |

## 3 Results

Figures 3 and 4 show the distributions of total phosphorus and chlorophyll-a in June and October. These maps were designed from Geographic Information System (GIS) by using Inverse distance weight process (IDW) [14].

The values of total phosphorus, chlorophyll-a, and water transparency in June and October were analyzed and shown in Table 3. In June, the total phosphorus changed between 16.56–49.01 µg/L, and site 1 was the highest values (Figure 3). The concentration of chlorophyll-a changed between 3.90–22.96 µg/L, and site 9 was the highest value (Figure 4), and the transparency ranged between 0.80–2.10 m. In October, total phosphorus changed between 23.50–53.95 µg/L, and site 8 was the highest values (Figure 3). The concentration of chlorophyll-a changed between 4.70–20.90 µg/L, and site 4 was the highest value (Figure 4), and the transparency ranged between 1.55–2.10 m.

The values of CTSI were calculated by analyzing three parameters; total phosphorus, chlorophyll-a and Secchi disk depth. It was observed that the values of CTSI from 13 sampling points ranged between 49.26 to 59.60 in June and 49.07 to 56.04 in October. Table 4 shows CTSI values in June and October. In June, most of sampling points were eutrophic except site 11 was

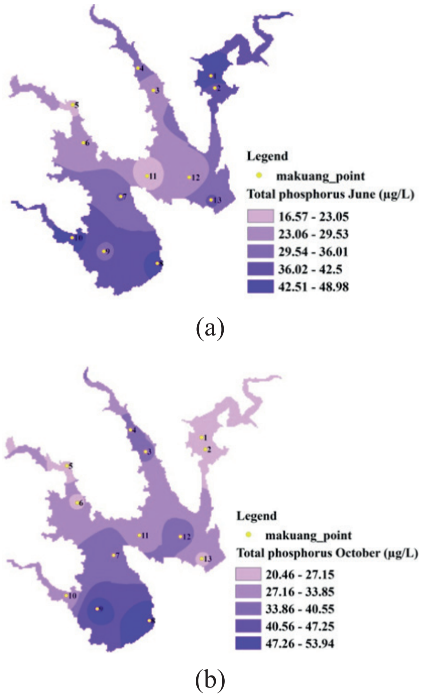


**Figure 3**: The distributions of total phosphorus contents in June and October.

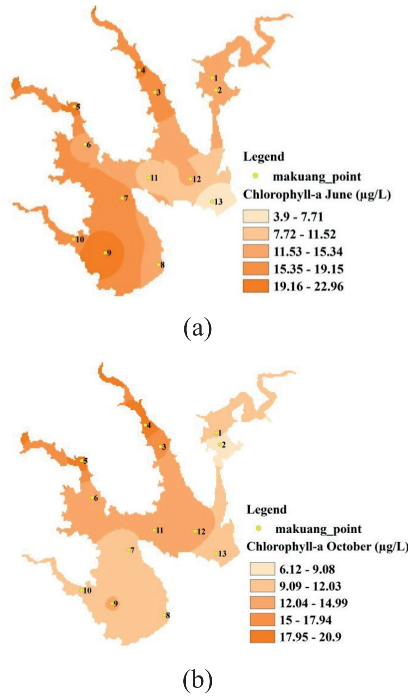


**Figure 4**: The distributions of chlorophyll-a contents in June and October.

**Table 3**: Values of total phosphorus, Chlorophyll-a, and Secchi disk depth of Mae Kuang Reservoir in June and October

| Site | Total P (µg/L) | | Chlorophyll-a (µg/L) | | Secchi Disk Depth (m) | |
|---|---|---|---|---|---|---|
| | June | October | June | October | June | October |
| 1 | 49.01 | 23.5 | 12.43 | 10.06 | 0.8 | 2.1 |
| 2 | 40.73 | 26.44 | 14.51 | 4.72 | 2.1 | 2 |
| 3 | 25.24 | 34.72 | 18.37 | 15.07 | 1.1 | 1.9 |
| 4 | 32.18 | 35.39 | 9.52 | 20.9 | 0.8 | 1.85 |
| 5 | 21.77 | 25.37 | 19.74 | 8.88 | 1.4 | 1.57 |
| 6 | 24.57 | 26.71 | 4.36 | 12.52 | 1.4 | 1.76 |
| 7 | 36.32 | 38.86 | 17.03 | 10.15 | 1.5 | 1.85 |
| 8 | 44.47 | 53.95 | 4.39 | 12.03 | 1.45 | 1.81 |
| 9 | 35.26 | 51.15 | 22.96 | 12.11 | 1.6 | 1.78 |
| 10 | 47.14 | 27.38 | 8.63 | 10.63 | 1.5 | 1.55 |
| 11 | 16.56 | 30.32 | 9.24 | 13.64 | 1.9 | 1.7 |
| 12 | 24.17 | 36.73 | 11.91 | 13.76 | 1.75 | 1.88 |
| 13 | 46.47 | 26.18 | 3.9 | 9.56 | 1.6 | 1.97 |

**Table 4**: Carlson's TSI values of Mae Kuang Reservoir in June and October

| Site | TSI (TP) | | TSI (Ch-a) | | TSI (SD) | | CTSI | | Trophic Status | |
|---|---|---|---|---|---|---|---|---|---|---|
| | June | October | June | October | June | October | June | October | June | October |
| 1 | 60.27 | 49.68 | 55.32 | 53.24 | 63.22 | 49.31 | 59.6 | 50.74 | Eutrophic | Eutrophic |
| 2 | 57.61 | 51.37 | 56.84 | 45.83 | 49.31 | 50.01 | 54.59 | 49.07 | Eutrophic | Mesotrophic |
| 3 | 50.7 | 55.3 | 59.15 | 57.21 | 58.63 | 50.75 | 56.16 | 54.42 | Eutrophic | Eutrophic |
| 4 | 54.21 | 55.58 | 52.71 | 60.42 | 63.22 | 51.14 | 56.71 | 55.71 | Eutrophic | Eutrophic |
| 5 | 48.57 | 50.78 | 59.86 | 52.03 | 55.15 | 53.5 | 54.53 | 52.1 | Eutrophic | Eutrophic |
| 6 | 50.32 | 51.52 | 45.04 | 55.39 | 55.15 | 51.85 | 50.17 | 52.92 | Eutrophic | Eutrophic |
| 7 | 55.95 | 56.93 | 58.41 | 53.33 | 54.16 | 51.14 | 56.17 | 53.8 | Eutrophic | Eutrophic |
| 8 | 58.87 | 61.66 | 45.11 | 55 | 54.65 | 51.45 | 52.88 | 56.04 | Eutrophic | Eutrophic |
| 9 | 55.52 | 60.89 | 61.34 | 55.06 | 53.23 | 51.69 | 56.7 | 55.88 | Eutrophic | Eutrophic |
| 10 | 59.71 | 51.88 | 51.75 | 53.79 | 54.16 | 53.68 | 55.21 | 53.12 | Eutrophic | Eutrophic |
| 11 | 44.63 | 53.35 | 52.41 | 56.23 | 50.75 | 52.35 | 49.26 | 53.98 | Mesotrophic | Eutrophic |
| 12 | 50.08 | 56.11 | 54.9 | 56.32 | 51.94 | 50.9 | 52.31 | 54.45 | Eutrophic | Eutrophic |
| 13 | 59.51 | 51.23 | 43.94 | 52.74 | 53.23 | 50.23 | 52.23 | 51.4 | Eutrophic | Eutrophic |

mesotrophic (CTSI = 49.26). In October, most sites were also eutrophic, except site 2 was mesotrophic (CTSI = 49.07). Figure 5 shows a radar graph of CTSI values from June and October for a comparison of 2 month-period.

It is indicated that Mae Kuang reservoir had a eutrophic status because all of the sampling points were in eutrophic status based on the average values of CTSI.

The results obtained in both months, as presented in Table 4, were compared by t-test at 95% confidence level and they were found not significantly different ($t_{critical}$ = 2.179, $t_{calculated}$ = 0.015 for TSI (TP), $t_{calculated}$ = 0.352 for TSI (Ch-a), $t_{calculated}$ = 1.225 for TSI (SD), $t_{calculated}$ = 1.082 for CTSI, DOF = 12) [15].

Figures 6 and 7 show the distribution of TSI of Mae Kuang Reservoir in June and October, respectively. These maps were also designed from GIS by using IDW process [14], in which it estimated the predicted values of TSI from each sampling point and showed that the zone of the trophic status of all Mae Kuang Reservoir. According to the Figures, it indicates that in June (Figure 6), the distribution of TSI were high from the inlets (site no. 1, 2, 3 and 4), and in the middle of the reservoir, the values of TSI was lower than the inlets. In contrast, in October (Figure 7), the TSI of the middle of the reservoir was higher than those of the inlets.

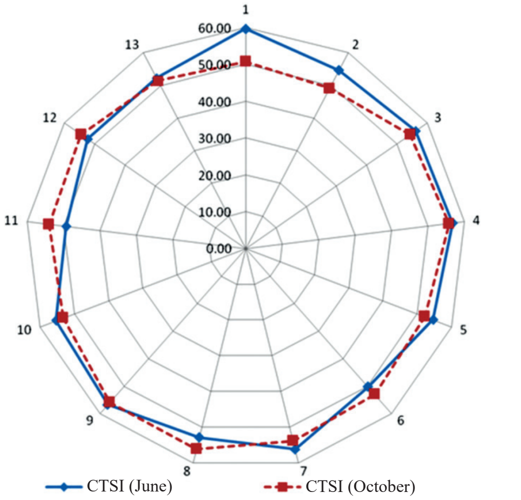


**Figure 5**: Radar graph of CTSI values for 13 sampling points of Mae Kuang Reservoir in June and October.

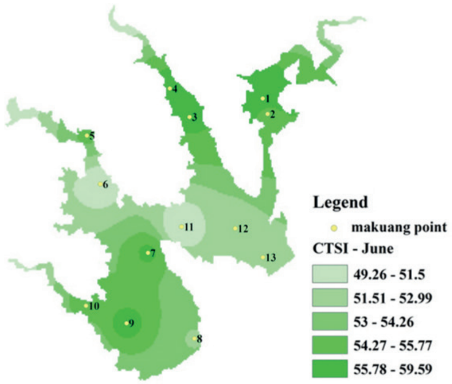


**Figure 6**: The distribution of TSI of Mae Kuang Reservoir in June.

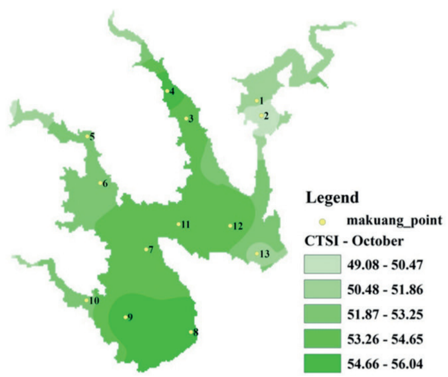


**Figure 7**: The distribution of TSI of Mae Kuang Reservoir in October.

## 4 Dicussion

Vollenweider [16] reported the assessment criteria for the lake trophic status based on the three parameters used for CTSI calculation, as shown in Table 5.

The results presented in Table 4 were compared to the values in Table 5. It showed that the ranges of total phosphorus contents in the reservoir from both seasons are in the state of eutrophic (16.56–49.01 µg/L and 23.50–53.95 µg/L). The chlorophyll-a concentration ranges from two seasons are 3.90– 22.96 µg/L and 4.70–20.90 µg/L that were classified in the eutrophic state. The water transparencies from two seasons were 0.8–2.1 m and 1.55–2.1 m, which were in the eutrophic state too. The results indicated that the reservoir was in the eutrophic state.

**Table 5**: The assessment criteria for the lake trophic status

| Parameter | Oligo Trophic | Meso Trophic | Eutrophic | Hyper Eutrophic |
|---|---|---|---|---|
| Transparency (m) | > 4 | 2–4 | 0.5–2 | 0.2–0.5 |
| Total phosphorus (µg/L) | <12 | 12–24 | 24–96 | 96–389 |
| Chlorophyll-a (µg/L) | < 2.6 | 2.6–20 | 20–56 | 56–155 |

This study indicated that the water quality of the reservoir is getting worse based on the previous studies as follows. In 1996, Mulsin [17] investigated the water quality of Mae Kuang Reservoir and concluded that the status of the lake was mesotrophic because the total phosphorus, and chlorophyll-a contents were not high. In 2004, Seekhow [18] had reported that the status of Mae Kuang Reservoir was in the oligotrophic to mesotrophic at the water surface, but in the deepest zone of water the status was eutrophic because of the nutrient accumulations.

Many factors can contribute to an increase in eutrophication, such as plant nutrients, temperature and light. Temperature is an important environmental factor that influences chemical and physical properties of water ecosystems such as pH, salinity, solubility, and diffusion rates, and consequently affects water eutrophication's potential [19]. When water temperature and phosphorus concentrations increase, algae growth is stimulated leading to water eutrophication and algal blooms [20], [21]. According to Mooij [19], warmer temperatures could also stimulate earlier and extend periods of potential algal blooms, as the immediate direct effect of a warmer environment. In these periods, the average temperatures in June and October were 30.9, and 29.6 °C, respectively, and this temperature range might encourage some algae's growth.

Light is an essential factor for the growth of algae and other aquatic species. Consequently, sufficient sunlight increases water temperature, and the presence of phosphorus also provides suitable conditions for the growth of algae, finally resulting in water eutrophication [22]. According to Nesa [23], light affects a wide range of living organisms, by penetrating aquatic systems and acts as the energy source for plant photosynthesis. If plants do not receive sufficient amounts of sunlight, they take up oxygen from the water, and dissolved oxygen depletion will occur.

In this work, we revealed that Carlson's TSI could evaluate the level of eutrophication. According to the results, Mae Kuang Reservoir was in a eutrophic state. This study selected 2 seasons for comparison: the summer season (June) and the rainy season (October). In summer or dry season, the high eutrophication was distributed at the inlet of the reservoir because these sites were the input of nutrients taken by water from the upper area. The sites were shallow, had turbid water, more light, and higher temperatures encouraging algae growth. Table 4 shows that the TSI values of all parameters (TP, Ch-a, and SD) in the inlet areas were higher than in the middle area of the reservoir. In the rainy season, the water inlet sites had CTSI lower than those of the summer season because the water level was higher, which are 100 million $m^3$ in October and 45 million $m^3$ in June.

In October, a higher eutrophic was found in the middle of the reservoir, which may be due to the transportation of the nutrients to the central area, as indicated by the high contents of TP and Ch-a at the middle sites. According to the results, human activities mostly encourage eutrophication, especially the phosphorus loading from sources, such as fertilizer, manure, and wastewater, which accelerate the algal bloom [24].

## 5 Conclusions

The Carlson's TSI was used to examine the eutrophic state of Mae Kuang Reservoir. It revealed that the situation of Mae Kuang Reservoir is a primary or low eutrophic state. The water quality of the reservoir is getting worse from the previous investigations. However, this eutrophic is not severe, the living organisms can survive, and water from this reservoir can be used for consumption and irrigation.

According to the trophic state results using three parameters, i.e., total phosphorus, chlorophyll-a, and water transparency (related to biomass amounts), the eutrophic status was found at the water inlet sites in summer and the middle sites of the reservoir in the rainy season. The cause of eutrophication in Mae Kuang Reservoir might be caused by the phosphorus loadings from runoff by Mae Kuang River, and the inlet sources were fertilizers and wastes from residents. Therefore, the prevention of nutrient loading to the reservoir is necessary to reduce eutrophication.

Increased phosphorus enrichment from external sources may further enhance phytoplankton biomass, and finally, the mass of phytoplankton may decrease dissolved oxygen, and the lake will be changed into an anoxic situation. Besides phosphorus content, temperature and light are essential factors for the growth of algae and cause algae to bloom, which lead to eutrophication.

The Carlson's TSI is a simple indicator of water pollution where biomass is implicated, because it uses three parameters for evaluating the eutrophic condition. It is suitable for examining the eutrophic state of lake ecosystems.

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