Water Environment Quality Evaluation and Measures of Kandy Lake in Sri Lanka under the background of “belt and road”

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Abstract: Water resources and water environment problems are serious in countries along the belt and Road, especially in Sri Lanka. Through collecting and analyzing water samples from 15 different areas and 3 different times of Kandy Lake, and evaluating water samples under spatial and temporal differences by Demerol index method, the improvement measures of Kandy Lake water quality can be put forward. The results show that there are significant spatial differences in the pollution indexes of Kandy Lake. The Nemero comprehensive pollution index of At Devon Hotel reaches 5.21, which is a serious pollution level, far higher than that of the Lake Center. At the same time, the pollution index of Kandy Lake was greatly affected by the difference of time and season. The Nemero comprehensive pollution index of Kandy Lake was 5.26 during the 12.03.2018 Rainy Weather, which is well ahead of 18.01.2018 Dry Weather and 20.06.2018 Partly Weather's 1.21 and 1.98. Therefore, according to the law of crowd activities, surface flow constructed wetlands are recommended to establish along the Bank of Kandy Lake with less crowd, while subsurface flow wetlands are recommended to establish along the coast of restaurant and Hotels with more crowd activities. Surface flow wetlands dominated by typical moist plant pools with emergent floating submerged vegetation are recommended to establish at the inlet, in order to improve the overall water quality of Kandy Lake. The research results can provide reference for water pollution control in Sri Lanka.

1. Introduction

“Belt and Road” is the abbreviation of the "Silk Road Economic Belt" and "twenty-first Century Maritime Silk Road", which is an initiative proposed by China to promote international and regional cooperation in the new era. It is a new model of cross regional cooperation to promote common development of economic globalization, achieve win-win cooperation and enhance China’s international influence and discourse power.[1-2]The Belt and Road initiative has long routes, covers a wide range of countries and also exist great geographical differences. As a result, the implementation of "Belt and Road" is faced with a serious situation -- water resources and water environment problem. Especially, the countries along “Belt and Road” are mainly developing countries, whose water environment problems is very prominent. These problems has brought uncertainty to the implementation and overall layout of the Belt and Road Initiative [3]. Sri Lanka is located at the "crossroads" of the Indian Ocean. It is an important partner country for China to build the "21st century Maritime Silk Road". Meanwhile, the solution of water environment problems is the main demand to promote local sustainable development. Sri Lanka has serious water pollution. As a result, a series of social health problems have appeared in its territory. For example, CKDu, which is highly prevalent in northern Sri Lanka, has caused more than 250000 cases of illness and death, becoming one of the most important public health problems in Sri Lanka. Some studies have shown that the serious exceeding of groundwater hardness and Fluorine ion concentration in Sri Lanka are one of the main causes of CKDu. [4] Therefore, it is very important to carry out local water environment investigation to analysis and formulate corresponding safety and security measures.

Reasonable evaluation methods and reflecting water quality accurately is the basis of solving water environment problems. Nowadays the common methods such as single factor evaluation method, Nemerow index method, and fuzzy mathematics method are mainly used in water environmental quality evaluation. Among them, Nemerow pollution index evaluation method is characterized by simple evaluation process and strong pertinence of evaluation results. So, it is widely used in the field of water quality evaluation. Ma Yi et al. used Nemero pollution index method to comprehensively evaluate the water quality of five sections of Fuxi River, and the results showed that the water quality of sections near the Institute Of Carbon was seriously polluted, with the annual average Nemero index value reaching 24.41. Its ammonia nitrogen, total nitrogen and fecal eschericosis groups exceeded the standard seriously, which were the main pollution factors [5].Wang Shujin and others applied the Nemero index method to four different areas of Yangzonghai lakeside wetland. The results showed that the Eutrophication Indexes of the four test wetland areas of Yangzonghai lakeside wetland were all good, while the evaluation results of heavy metal indexes are that the East and north belong to moderate pollution level, and the South and West belong to severe pollution level. The total average mass concentration of TP is 0.095mg / L, which is 1.9 times of relevant standards, and the pollution of As is the most serious, which is 0.112mg/l.[6]

At present, there are many research achievements based on Nemero pollution index evaluation in China. Though too much dynamic factors, the large amount of water quality monitoring data, and poor regularity make the water quality evaluation in the Belt and Road related countries less research. Nowadays there is a problem of water quality deterioration in Kandy area, Sri Lanka. Therefore, this study takes Kandy Lake as the research object, based on the collection and analysis of local existing research data, combined with the results of field investigation and sampling analysis, systematically describes the current situation and problems of water environment in Sri Lanka, reveals the risk characteristics of water quality of local lakes [7], and then puts forward a feasible scheme of ecological protection. At the same time, it provides experience for solving water environment crisis in other areas with similar environment as Kandy, as well as southeast and South Asian countries along the "Belt and Road".

2. Overview of the study area

Sri Lanka is a tropical island country in the Indian Ocean. It is located at the southern end of the South Asian subcontinent, facing the Indian peninsula across the Balk Strait in the northwest, covering an area of 65,610 square kilometers.[8]Kandy is the second largest city in Sri Lanka, located in the central mountains of Sri Lanka, founded in the 14th century, is a famous Buddhist shrine, also known as the Holy City of Kandy.[9]Kandy Lake, a giant artificial lake dug from a rice field in the heart of Kandy, is one of the city's most famous tourist attractions. Because this place is located in the tropical area, there are higher mountains in the north of the city, so it has a typical tropical monsoon climate, the average annual temperature is 18 degrees and the climate is relatively humid. There are two periods of good rainfall each year: April-June, and October-December [10]. Due to serious groundwater pollution, Kandy suffers from severe water shortage during the dry season when rainfall is low.

3. Methods of sample collection and analysis

The samples were collected and stored according to standard test methods for drinking water (GB / T5750-2006) and methods for monitoring and analysis of water and wastewater (Fourth Edition). The sampling and storage of Sri Lanka samples shall be based on the existing methods and meet the requirements of the local drinking water standard Sri Lanka standards for potable water - SLS 614:2013 (hereinafter referred to as SLS 614:2013).

Conventional water quality detection methods include single index evaluation method, comprehensive index evaluation method, Nemero pollution index evaluation method, etc. because the first two have the disadvantages of cumbersome data and insufficient pertinence, this paper will use Nemero pollution index evaluation method. Nemero index method is one of the most widely used

water quality analysis methods, and it is a weighted polyphonic word that takes into account both extreme value and average value. The calculation formula of environmental quality index [8] is as follows:

$$P = \sqrt{\frac{(c_i / S_i)^2_{\max} + (c_i / S_i)^2_{ave}}{2}} \quad (1)$$

Where P is the Nemerol index; C is the actually measured mass concentration;

S_i is the maximum allowable mass concentration;

$(C_i / S_{i)\,max}$ is the maximum value of the comprehensive pollution index;

$(C_i / S_i)_{ave}$ is the average value of the comprehensive pollution index.

And the grade evaluation and classification standards of Nemero water quality comprehensive pollution index are shown in Table 1.

Table 1. Nemero water quality index pollution grade.

Nemero comprehensive pollution index				
P<1	1≤P≤2	2<P≤3	3<P≤5	P>5
Clean water quality	Slightly Polluted	contaminated	Heavy Polluted	Serious Polluted

4. Result analysis

Through water sample extraction and detection records in 15 different areas around Kandy Lake, such as Kandy cultural center, publishing Buddhist Association, Kandy Lake Center, at Devon Hotel, and in three different seasons, such as dry season in January, rainy season in March and partly weather in June, were analyzed to obtain relevant data and select the most representative five groups, as shown in Table 2.

Table 2. Water quality analysis data of the Kandy Lake.

Date	Parameter	Buddhist Publication Society	Kandy Cultural Centre	Awanhala Restaurant	Middle of the Lake	At Devon Hotel
18.01.2018 Dry Weather	COD	11	7	9	16	14
	DO	3.34	3.62	6.51	7.17	5.43
	Nitrate/ NO_3^-	6.4	0.8	0.8	0.6	1.7
	Phosphate/PO_4^{3-}	0.22	0.08	0.23	0.26	1.28
	UIA	>0.09485	0.00506	0.01531	0.000519	0.02415
12.03.2018 Rainy Weather	COD	55	44	51	30	72
	DO	6.51	3.01	4.85	5.49	5.09
	Nitrate/ NO3-	11.11	7.5	4.8	3.8	51.5
	Phosphate/PO43-	0.84	0.06	4.88	4.24	1.53
	UIA	0.1171	0.020608	0.0309	0.001872	>0.0182
20.06.2018 Partly Weather	COD	27	19	14	16	27
	DO	6.88	3.27	6.06	6.69	6.05
	Nitrate/ NO3-	5.4	2	1.5	1.2	4.6
	Phosphate/PO43-	0.55	0.13	0.02	0.01	1.27
	UIA	0.005244	0.006486	0.001035	0.001656	0.02415

It can be seen from Fig. 1 that the relevant pollution indicators of Kandy Lake are significantly affected by spatial differences. In terms of the average mass concentration of COD, the overall average mass concentration of COD in Kandy Lake is 27.47mg·L^{-1}, which is 2.7 times higher than the relevant standards, The average mass concentration of COD in the water sample located in At Devon Hotel is 37.67mg·L^{-1}; while the annual average mass concentration of COD in the center of the lake

is 20.67mg·L^{-1}, which also exceeds the standard of 10mg·L^{-1}. However, it is much lower than At Devon Hotel, while those of Buddhist Publication Society, Kandy cultural centre and Awanhala Restaurant are 31.00;23.33;24.67mg·L^{-1}respectively.The overall water quality is greatly affected by organic matter.

Table 2 shows that the Nemero comprehensive pollution index of Kandy Lake in different locations ranges from 2.21 to 5.21, which is the level of contaminated to heavy polluted. The order of Nemero index of five different sampling points is At Devon Hotel > Buddhist Publication Society > Awanhala Restaurant > Kandy Cultural Centre > Middle of the Lake. The Nemero Composite pollution index at the At Devon Hotel reached 5.21, which is a serious polluted level. The P index of Middle of the Lake is 2.21, though it also belonging to the contaminated level, it's far lower than the other four areas. The results indicate that the coastal zone of Kandy Lake is more polluted by point source and non-point source, which is mainly due to the increase of surrounding social activities and pollution emissions with the increase of tourists in recent years.

From the above analysis, it can be inferred that the pollution of water quality is obviously related to the population activities form the monitoring points. Areas with more domestic and production activities may be accompanied by a large number of illegal discharge of domestic sewage containing phosphorus and sulfur, resulting the serious exceeding of various pollution indexes in the nearby waters. Publishing houses like Buddhist publication society often produce a large number of industrial sewage, so the contamination condition of its near water area is also very serious. And the pollution index in the center of the lake, for which has almost none life and production activities, is the lowest, can also supports this speculation.

Table 3. Nemero index under spatial difference of Kandy Lake.

Area	P	Water quality evaluation
Buddhist Publication Society	3.99	Heavy polluted
Kandy Cultural Centre	3.15	Heavy polluted
Awanhala Restaurant	3.67	Heavy polluted
Middle of the Lake	2.21	contaminated
At Devon Hotel	5.21	Serious polluted

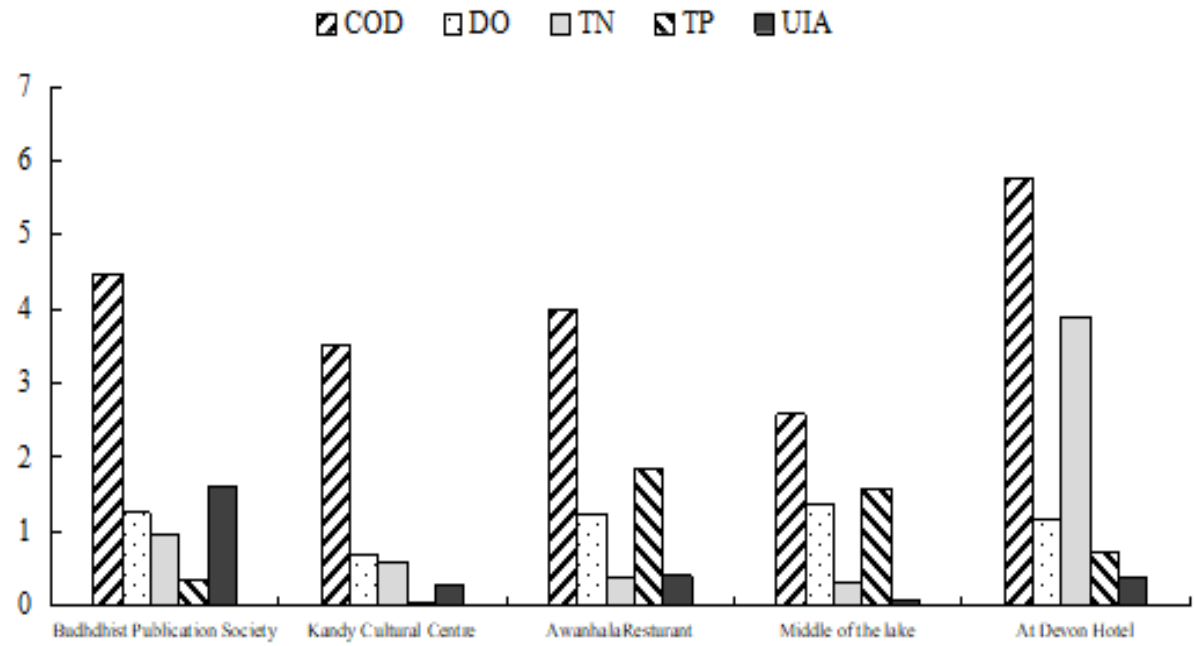

Fig 1. Relevant pollution indicators on spatial difference of Kandy Lake.

It can be seen from Figure 2 that the pollution index of Kandy Lake is greatly affected by the time and season difference. In terms of the average mass concentration of TN, the overall average mass

concentration of TN in the whole year is 6.914mg·L^{-1}, slightly lower than the quality standard of 10mg·L^{-1}. However, by analyzing different time and seasons, the average mass concentration of TN in Kandy Lake of 12.03.2018 Rainy Weather reached 15.742 mg·L^{-1}, which is 1.5 times of the standard. But the average TN mass concentration of Kandy Lake is 2.06mg·L^{-1} and 2.94mg·L^{-1} respectively at 18.01.2018 Dry Weather and 20.06.2018 Partly Weather, which are far lower than the relevant standards. While at 12.03.2018 rain weather, the mass concentration of COD is 50.4mg·L^{-1}, are 5 times and 2.5 times higher than which at 18.01.2018 dry weather (11.4mg·L^{-1}) and 20.06.2018 party weather (20.6mg·L^{-1}) respectively.

It can be seen from table 4 that the Nemero comprehensive pollution index value of 12.03.2018 Rainy Weather is 5.26, which belongs to the level of serious polluted; while the Nemero indexes of 18.01.2018 Dry Weather and 20.06.2018 Partly Weather are 1.21 and 1.98 respectively, which belong to the level of Slight Polluted. Therefore, it can be concluded from the data that the water quality of Kandy Lake is the most polluted during the rainy season in March, meanwhile the water quality in January dry season and June partly weather is much better than the former.

Consequently, it can be inferred from the above analysis that the water pollution of Kandy Lake is related to its season and rainfall. Firstly, March is the farming and planting period, a large amount of phosphorus and nitrogen fertilizers are washed into the lake by rain, resulting in a sharp rise of TP and TN. Secondly, due to the increase of rainfall, all kinds of domestic garbage on the urban surface, such as phosphorus containing detergent and catering sewage, are washed into the groundwater and finally collected in Kandy Lake. Furthermore, due to rising water level caused by frequent rainfall, the content of dissolved oxygen DO in the lake decreases, resulting in the aerobic bacteria and anaerobic bacteria in the bottom sludge can transform the mud nitrogen element into the lake through nitrification and denitrification.

Table 4. Nemero comprehensive pollution index under time difference of Kandy Lake.

Date	P	Water quality evaluation
18.01.2018 Dry Weather	1.21	Slight pollution
12.03.2018 Rainy Weather	5.26	Serious pollution
20.06.2018 Partly Weather	1.98	Slight pollution

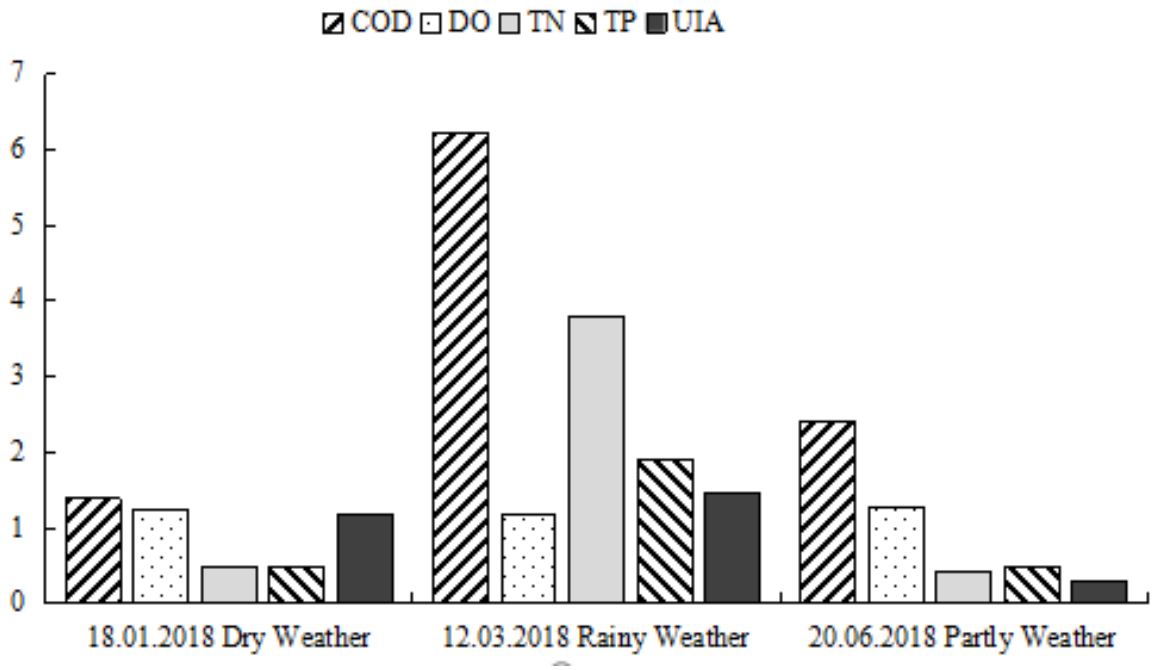

Fig 2. Relevant pollution indicators on time difference of Kandy Lake.

It can be seen from Figure 2 that except TN and TP can meet the water quality standards in specific time and season, the overall pollution index of Kandy Lake exceeds the standard seriously, which

shows that water quality is not optimistic. The annual average COD mass concentration is 27.47 $mg \cdot L^{-1}$, 2.7 times of the local standard, as well as the average COD mass concentration in rainy season is 50.4 $mg \cdot L^{-1}$, 5 times of the relevant standard. In addition, some areas' surrounding water pollution is also extremely serious. For example, in At Devon Hotel, the annual average COD concentration is 37.667$mg \cdot L^{-1}$, which is 3.7 times higher than the relevant standard, while the annual average value of TN in its surrounding waters is $mg \cdot L^{-1}$, which also far higher than the standard of < 10$mg \cdot L^{-1}$. Therefore, it is urgent to improve the quality of Kandy Lake.

5. Measures to ensure water quality of Kandy Lake

As the water pollution in Kandy Lake is mainly due to the excessive COD and TN values, which change greatly with time and space. There are many tourists around Kandy Lake in daily life. Therefore, it is recommended to construct several different types of artificial landscape wetlands along the Kandy Lake according to different geographical characteristics and different locations, to reduce the influence of non-point source pollution on the water quality of Kandy Lake in rainy season. On the basis of the law of crowd activity, the surface flow constructed wetland could be built along the Kandy Lake, where less crowded, for tourists to enjoy. At the same time, underflow wetlands could be established in areas with more crowd activities, such as hotels, hotels and typical coastal areas, to purify point source pollution.

The water quality pollution is relatively mild with less human activities based on former data. So to establish an Emergent-floating-submerged vegetation hygrophilous plant pool surface flow wetland at the inlet, can fully intercept, settle and absorb the sludge and sewage brought by urban underground facilities. It can cut down the river pollution load, increase the dissolved oxygen waters, the water self-purification ability and the ability of flood detention, in order to reduce the impact of water pollution brought by rainy season to a certain extent. The establishment of vertical subsurface flow wetland in areas with more crowd activities can not only increase the landscape diversity and biodiversity, but also form a sewage treatment tank with AAO biological method. Through nitrification, denitrification and sedimentation, it can greatly reduce the pollution indexes such as TN, BOD and TP in Kandy Lake, to achieve the overall improvement of the water quality of Kandy Lake.

6. Conclusion

(1) The average mass concentration of COD in Kandy Lake is 27.47$mg \cdot L^{-1}$, 2.7 times that of the local surface water standard. The annual average COD concentration of water samples in the Lake center was 20.67$mg \cdot L^{-1}$, which was much lower than 37.67, 31.00, 23.33 and 24.67$mg \cdot L^{-1}$ of the other four sampling sites. The spatial difference of relevant pollution indexes was obvious.

(2) The COD mass concentration of rain weather on 12.03.2018 was 50.4 $mg \cdot L^{-1}$, which was 5 times and 2.5 times that of dry weather (11.4$mg \cdot L^{-1}$) on 18.01.2018 and partly weather (20.6$mg \cdot L^{-1}$) on 20.06.2018, respectively. The pollution index was greatly affected by time and season differences.

(3) The results of Nemero evaluation shows that the coastal area of Kandy Lake with more population activities and which in the rainy season after March are the most seriously polluted.

(4) It is suggested to establish surface flow constructed wetlands along the Bank of Kandy Lake with less crowd, establish subsurface flow wetlands in areas with more crowd activities, such as restaurants, hotels and classic banks, and establish surface flow wetlands dominated by typical hygrophytic plant pools with emergent floating submerged vegetation at the inlet, so as to improve the overall water quality of Kandy Lake.

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