Assessment of Nhong Han Lake, Sakon Nakhon, Thailand by Using Water Quality Index

Rathanit Sukthanapirat, Samonporn Suttibak, and Piyanuch Jaikaew

***Abstract*— *Water quality in Nhong Han lake, Sakon Nakhon, Thailand was assessed by using Mekong River Commission water quality indices (MRC-WQI). MRC-WQI was used to indicate the water quality for three main purposes namely (1) Water quality index for the protection of aquatic life (WQIal) (2) Water Quality Index for the Protection of Human Health with a focus on Human Acceptability (WQIhi) and (3) Water quality index for agricultural use (WQIag), which is divided into two categories: (i) general irrigation, (ii) paddy rice. MRC-WQI was analyzed by using 8 parameters namely, pH, Electrical conductivity (EC), Ammonia Nitrogen (NH_3-N), Dissolved Oxygen (DO), Nitrate (NO_3-N), Total Phosphorus (TP) Chemical Oxygen demand (COD), and Biochemical Oxygen Demand (BOD). The results indicated the current situation of Nhong Han Lake. As the results, water quality in community area evident on some parameters such as DO, COD and NH_3-N in WQIhi and WQIal have shown an impact of various anthropogenic activities. However, water quality in Nhong Han shown good quality for agricultural use. MRC-WQI is suggested as the tool to determine the water quality for decision makers for water management in Nhong Han lake.*

***Keywords*— MRC water quality indices, Nhong Han lake, Thailand, water quality index, water resources.**

1. INTRODUCTION

Nhong Han Lake is the largest natural fresh water lake in North Eastern, Thailand. The lake is an integral part of the local community and serves as their source of drinking water, fishery, and agriculture. With the expansion of Sakon Nakhon city (adjacent to the lake), there has been a continuous increase in water use from lake and wastewater discharge into the lake. Currently, there are two main water treatment plants that produce and supply potable water to Sakon Nakhon City. Wastewater from the city is processed in the two wastewater treatment plants (natural treatment system) prior to discharging into the Lake. In this study, we also observed that there are some points where wastewater is directly discharged without any treatment/buffer. This causes problems to the communities living around the lake due to excessive pollution. However, there are some agricultural communities on the other side of lake growing rice; these communities discharge fertilizer and pesticide into the lake [1]. Due to these factors, there is some eutrophication in the lake water that accelerates the growth of aquatic plants. After mutuality, these aquatic plants die and settle down to the bottom of the lake leading to the loss of its water holding capacity of the lake.

Water quality in the Nhong Han Lake is periodically monitored every 3 months by the 9th Regional Environment Office (Thailand). The Water quality parameters are assessed based on water quality index provided by the Pollution Control Department (PCD-WQI), Thailand with five water quality parameters namely, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Total Coliform Bacteria, Fecal Coliform Bacteria and Ammonia-Nitrogen [2]. Based on these factors, data are compared with a standard developed by PCD-WQI for surface water quality and classified into five classes. The standard surface water quality define water utilization in each class such as Class 1: Extra clean for conservation purposes Class 2: Very clean used for (1) consumption which requires ordinary water treatment processes (2) aquatic organism conservation (3) fisheries, and (4) recreation [DO > 6 mg/L, BOD < 1.5 mg/L, Fecal Bacteria < 1000 MPN/100mL) Class 3: Medium clean used for (1) consumption but passing through an ordinary treatment process and (2) agriculture [DO > 4 mg/L, BOD < 2 mg/L, Fecal Bacteria < 4000 MPN/100mL) Class 4: Fairly clean used for (1) consumption, but requires special treatment process and (2) industry [DO > 2 mg/L, BOD < 4 mg/L) Class 5: Waters are not classification in class 1-4 and used for navigation [3].

There are several methods to analyze water quality data depending on the information goals, the type of samples, and the size of the sampling area [4]. Suitable water quality indices are available which are effective to communicate information on water quality trends [5]. This is based on the value of various water quality parameters in physico-chemical and biological parameters. In addition, it can be the used as a decision tool for management strategies for improving water quality [6]. The water quality level is represented by an

Rathanit Sukthanapirat (corresponding author) is with Department of Civil and Environmental Engineering, Faculty of Science and Engineering, Kasetsart University Chalermphrakiat Sakon Nakhon Province Campus, Sakon Nakhon 47000 Thailand. Phone: +66-87-324-6145; Fax: +66-04-272-5034; E-mail: phonthida.s@ku.th.

Samonporn Suttibak is with Department of Civil and Environmental Engineering, Faculty of Science and Engineering, Kasetsart University Chalermphrakiat Sakon Nakhon Province Campus, Sakon Nakhon 47000 Thailand. E-mail: samonporn.s@ku.th.

Piyanuch Jaikaew is with Department of Civil and Environmental Engineering, Faculty of Science and Engineering, Kasetsart University Chalermphrakiat Sakon Nakhon Province Campus, Sakon Nakhon 47000 Thailand. E-mail: piya_e56@yahoo.com.

index, which is a numerical expression used to transform many variables into a single number [7]. Literature presents numerous studies for water quality assessment using water quality index [8-10] MRC-WQI is the water quality indices that is currently being used to express overall water quality of the Mekong River and its tributaries based on several water quality parameters. The indices comprise of; (1) Water quality index for the protection of aquatic life (WQIal) (2), Water quality index for human impact on water quality (WQIhi) and (3) Water quality index for agricultural use (WQIag), which is divided into two categories: (i) General irrigation, (ii) Paddy rice [11]

As this study was conducted to better understand the impact of water quality of the lake due to human activities such as agriculture, drinking water extraction, wastewater disposal, and protection of aquatic life. Therefore, MRC-WQI was used as it closely matched these requirements for making better policies and strategies for water management in Nhong Han Lake.

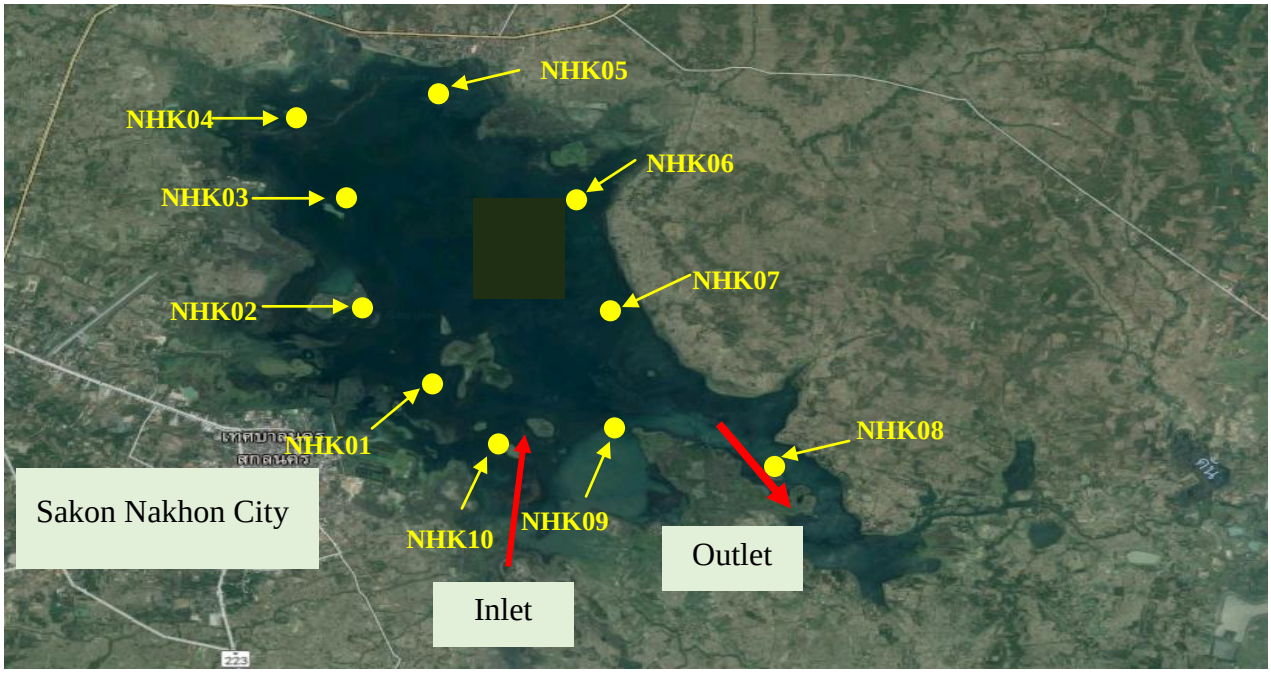

Fig.1 Sampling point in Nhong Han Lake.

2. METHODOLOY

Description of the Study Sites and Sample collection

Nhong Han Lake is 123 km² with a capacity of about 266.92 x 10^6 m^3. A total of 10 sampling stations around the lake where selected, which would represent 10 sub-districts with 38 villages. There are 21 creeks which are water inlets for Nhong Han Lake. The major outlet for the lake is located at Nhom Kum creek at the bottom of the lake as presented in Figure 1. The details of sampling point of each sub-districts shown in Table 1. The study sites are classified into two main areas such as community areas (NHK01, NHK02, NHK03, NKH04 and NHK05) and agricultural areas (NHK06, NHK07, NHK08, NHK09 and NHK 10). The position of sampling points presented in Fig.1. Sampling was done in July 2016. MRC-WQI was analyzed using 8 parameters namely, pH, EC, NH3-N, DO, NO3-N, TP, COD, and BOD. The samples were analyzed following methods in the Standard Method for Examination of Water and Wastewater [12] Water samples were preserved at 4°C. To analyze as fast as possible pH, DO and EC were measured at the location using a portable measurement devices (HACH No.58258-00).

Table 1. Sampling Station

Station	Location	Coordinates
NHK01	Pumping station of Water treatment plant in Sakon Nakhon city	N0410394 E1898570
NHK02	Community area in Sakon Nakhon	N0408570 E1900150
NHK03	Hanghong sub-district	N0408819 E1905437
NHK04	Chiangkrua Sub-district	N0409324 E1906248
NHK05	Pumping station of Water treatment plant in Tharae Sub-district	N0413026 E1907395
NHK06	Banpan Sub-district	N0416467 E1900889
NHK07	Thasara, Jomjaeng Village	N0419727 E1897333
NHK08	Natongwattana Sub-district	N0423341 E1896691
NHK09	Laopodeang Sub-district	N0415168 E1896155
NHK10	Ngew-don Sub-district	N0414038 E1896472

Application of the WQI

The Water Quality Index for the protection of Aquatic Life is calculated using Equation 1, six parameters were included which are listed in Table 2. The classification system for the Water Quality Index for the Protection of Aquatic Life is summarized in Table 3.

$$WQI = \frac{\sum_{i=1}^{n} p_i}{M} \times 10 \quad (1)$$

where, p_i is the points scored on the sample. If each parameter listed in Table 2 meets its respective target value in Table 2, its corresponding weight factor is scored; otherwise, a default score of zero is assigned, n is the number of samples from the station in the year. M is the maximum possible score for the measured parameters in the year.

Table 2. Parameters used for calculating the rating score of the Water Quality Index of the Water Quality index for the Protection of Aquatic Life with their target values

Parameters	Target values
pH	6-9
EC (mS/m)	< 150
NH_3 (mg/L)	0.1
DO (mg/L)	> 5
$NO_{2\text{-}3}$-N (mg/L)	0.5
T-P	13

Table 3. Rating systems for the Water Quality Index for the Protection of Aquatic Life

Rating Score	Class
9.5 ≤ WQI ≤ 10	A: High quality
8 ≤ WQI ≤ 9.5	B: Good quality
6.5 ≤ WQI ≤ 8	C: Moderate quality
4.5 ≤ WQI ≤ 6.5	C: Poor quality
WQI < 4.5	C: Very poor quality

The Human Acceptability Index utilized parameters of indirect impact, as identified by human health risk index utilizes direct impact parameters. The rating score are calculated using Equation 2, which are based on the Canadian Water Quality index [13]. The list of parameters that were included in the calculation of the rating score for human health acceptability index with their target values are listed in Table 4. The classifications of system for the water quality index for the Protection of Human Health-Human Acceptability index are summarized in Table 5.

$$\mathrm{WQI} = 100 - \left(\frac{\sqrt{\mathrm{F_1^2}+\mathrm{F_2^2}+\mathrm{F_3^2}}}{1.732}\right) \quad (2)$$

where, F_1 is the percentage of parameters which exceed the guidelines and can be calculated by Equation 3. F_2 is the percentage of individual tests for each parameter that exceeded the guideline and can be calculated by Equation 4. F_3 is the extent to which the failed test exceeds the target value and can be calculated by Equation 5. Where nse is the sum of excursions and can be calculated using Equation 6. The excursion is calculated by Equation 7.

$$\mathrm{F_1} = \left(\frac{\#\ \text{offailedparameters}}{\text{Total \# ofparameters}}\right) \quad (3)$$

$$\mathrm{F_2} = \left(\frac{\#\ \text{offailedtests}}{\text{Total \# oftests}}\right) \quad (4)$$

$$F_3 = \left(\frac{nse}{0.01nse+0.01}\right) \quad (5)$$

$$nse = \left(\frac{\sum excursion}{Total\ \#\ of tests}\right) \quad (6)$$

$$excursion = \left(\frac{failedtestvalue}{guidelinevalue}\right) - 1 \quad (7)$$

Table 4. Parameters used for calculating the rating score of the Water Quality index for the Protection of Human Health-Human Health Acceptability index with their target value

Parameters	Target Values
pH	6-9
EC (mS/m)	< 150
NH_3 (mg/L)	0.5
DO (mg/L)	4
NO_3-N (mg/L)	5
COD (mg/L)	5
BOD (mg/L)	4

Table 5. Rating systems for the Water Quality index for the Protection of Aquatic Life

Rating Score	Class	Description
95 ≤ WQI ≤ 100	A: High quality	All measurements are within objectives virtually all of the time
80 ≤ WQI ≤ 95	B: Good quality	Conditions rarely depart from desirable levels
65 ≤ WQI ≤ 80	C: Moderate quality	Conditions sometimes depart from desirable level
45 ≤ WQI ≤ 65	C: Poor quality	Conditions often depart from desirable levels
WQI < 45	C: Very poor quality	Conditions usually depart from desirable levels

Water Quality Index for agricultural use focuses on water quality for general irrigation and paddy rice. The indices for general irrigation and paddy rice are calculated based on water quality guidelines for salinity (electrical conductivity, mS/m at temperature 25°C). The degree of consequence for the general irrigation and paddy rice indices are outlined in Table 6.

Table 6. Electrical conductivity guidelines and degrees of consequence for Water Quality index for Agricultural Use-general irrigation and paddy rice

Irrigating raw water	Degree of Consequence		
	None (Good)	Some (Fair)	Severe (Poor)
General irrigation (EC_mS/m)	< 70	70 - 300	> 300
Paddy rice (EC_ms/m)	< 200	200 - 400	> 480

3. EXISTING SITUATION OF WATER QUALITY IN NHONG HAN LAKE

As per the 9th Regional Environment Office, 2015 [14], PCD-WQI indicated overall water quality in Nhong Han Lake before 2014 was at a good level (Class 2). However, since then water quality has been progressively deteriorating. Water quality in the dry season was polluted than the rainy season because the additional water from creeks which caused water circulation in the lake. Whereas during the dry season, the water level in the lake decreased and the water was stagnant. The significant problems which were highlighted on the water quality parameters were low DO and it contaminated with fecal coliform bacteria FCB from domestic wastewater. Suttibak (2015) study the change in water quality in the lake using questionnaire with 326 samples. The results revealed that fishermen were affected by the change in water quality during rainy season due to high turbidity. This caused a decrease in fishing. Moreover, due to the increased pollution levels, some people in direct contact with the water developed rashes. The questionnaire also revealed that the water at times had a foul smell. The current situation of two wastewater treatment plants presents that they are not being utilized to their full capacity and did not cover all wastewater from the city [1]. Implying some of wastewater was discharged directly without any treatment into the lake.

4. RESULTS AND DISCUSSION

Analysis of MRC-WQI was conducted utilizing water quality data obtained from the lake as presented in Table 7. The results of each water quality index are presented below.

Water quality index for the protection of aquatic life (WQIal)

Analysis of water quality index for the protection of aquatic life indicates that water quality in the lake was of moderate to good quality for the protection of aquatic life. However, in most cases, water quality in the lake for the protection of aquatic life in the water was classified as Class C (moderate) based on the MRC-WQI. Including samples collected at NHK01, NHK04, NHK05, NHK07, NHK09, and NHK10. Class B (good quality) was assigned for aquatic life for the following sampling stations NHK02, NHK03, NHK06, and NHK08. Consideration should be given to nutrient removal. Especially, ammonia nitrogen is toxic to aquatic life.

Water Quality Index for the Protection of Human Health with a focus on Human Acceptability (WQIha)

The water quality index for the protection of human health was assessed based on 10 sampling locations. The WQIha analysis found that the water quality was classified as fair to good level in the lake. The water qualities in some places were classified as Class C (NHK01, NHK02, NHK03, NHK04, and NHK06). These sampling stations are in the community areas. These sampling stations, which showed relatively high COD and low DO due to the high organic matter decomposition. Water samples collected from sampling stations (NHK05, NHK07, NHK08, and NHK10) were classified as Class B (good level). NHK09 sampling location was classified as Class A with very good level of water quality for the protection of human health.

Table 7. Summary of Nhong Han Lake water quality

Sampling station	Water quality parameters							
	pH	EC (mS/m)	DO (mg/L)	NH_3-N (mg/L)	COD (mg/L)	BOD (mg/L)	TP (mg/L)	Nitrate (mg/L)
NHK01	7.55	27.8	1.72	0.11	32.0	2.20	0.01	0.46
NHK02	6.92	35.3	1.93	0.03	51.2	6.25	0.00	0.38
NHK03	7.62	14.9	1.14	1.09	38.4	3.00	0.00	0.20
NHK04	7.36	8.58	2.30	0.17	28.8	3.00	0.06	0.38
NHK05	7.23	21.2	6.34	0.12	16	<2	0.00	0.80
NHK06	7.47	11.9	7.16	0.21	25.6	<2	0.09	0.18
NHK07	7.55	13.9	6.35	0.25	16.0	<2	0.08	2.48
NHK08	7.60	17.8	4.16	0.20	9.6	<2	0.08	0.26
NHK09	7.60	8.35	5.26	0.15	6.4	<2	0.01	0.51
NHK10	7.41	18.4	4.53	0.11	19.2	3.36	0.07	0.23

Table 8. Results of MRC-WQI in Nhong Han Lake

Sampling station	Quality index for the protection of aquatic life (WQIal)	Quality index for the protection of human health with a focus on human acceptability (WQIhi)	Quality index for agriculture use (WQIag)	
			General irrigation	Paddy rice
NHK01	C	C	A	A
NHK02	B	C	A	A
NHK03	C	C	A	A
NHK04	C	C	A	A
NHK05	C	B	A	A
NHK06	B	C	A	A
NHK07	C	B	A	A
NHK08	B	B	A	A
NHK09	C	A	A	A
NHK10	C	B	A	A

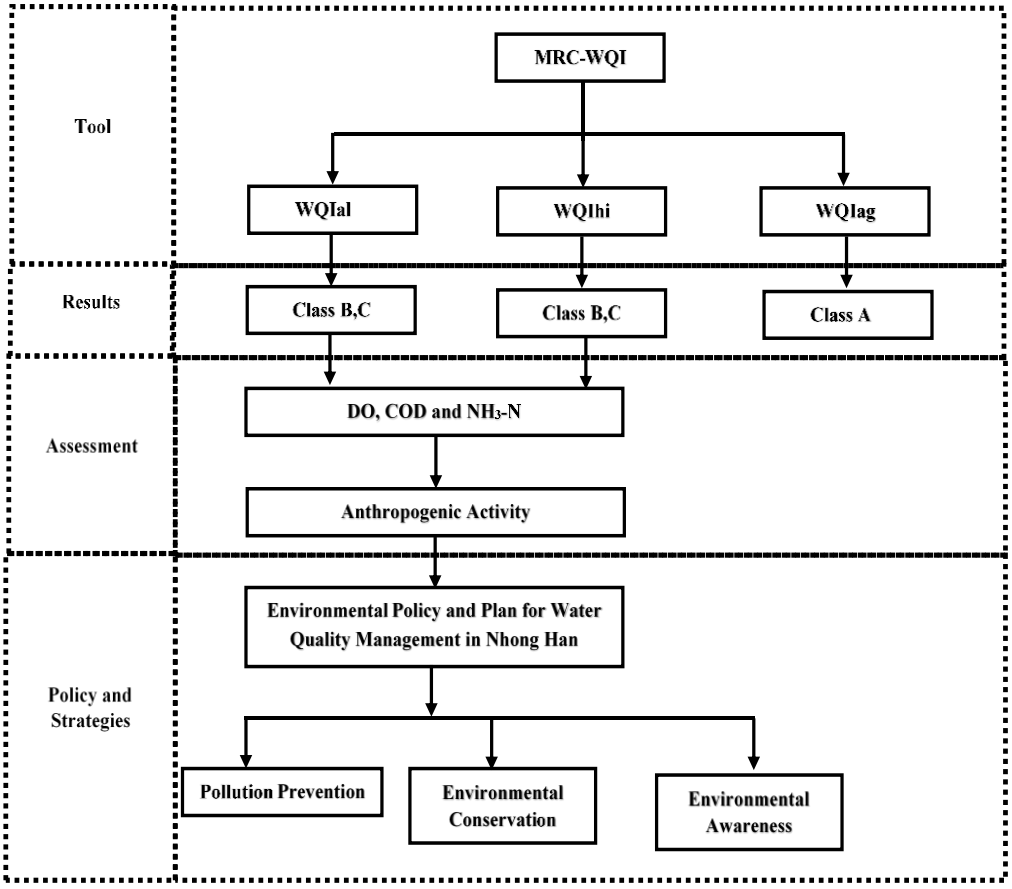

Fig.2 Application of MRC-WQI for water quality management in Nhong Han Lake.

Water Quality Index for Agricultural Use (WQIag)

Water quality index for agriculture assessed by electrical conductivity from MRC (2015) [11] the analysis of water quality for agriculture used are of two types; this includes water quality index for general irrigation and paddy field. The analysis found that the water quality index for irrigation was at a very good level and was classified as Class A. Also, the water quality in the lake was suitable for irrigation and was used in paddy fields. In general, the water quality in the lake was found to be suitable for the irrigation, agricultural and paddy field.

Assessment Results

As per the results, the water quality in Nhong Han Lake was of moderate level for human use and protection of aquatic life in some sampling points. Application of MRC-WQI for water quality management in Nhong Han

Lake is shown in Fig. 2. The result of this study could be used by the decision makers for the management of the quality of the lake water. The most polluted water was found in community areas and was due to the anthropogenic activities. This polluted water had a high COD, low DO and excess NH_3-N in some sampling points. Environmental policy and plan needs actions on pollution prevention, environmental conservation and create environmental awareness. The possible strategies to implement on pollution prevention such as the local government take serious action on household wastewater discharge. Moreover, on-site treatment should be applied for households as pretreatment before discharging into the lake. Wastewater collection system and wastewater treatment plant should be re-designed and reconstruct to support wastewater from the city. Water quality monitoring needs to monitor the wastewater discharge in all creek and wastewater discharge points. Furthermore, environmental conservation and create environmental awareness of people around Nhong Han Lake should be promoted. Water quality monitoring in Nhong Han should be investigated every year. These investigations can assess the potential of pollution prevention strategies. Additionally, ecosystem conservation with people participation should be implemented. Awareness programs should be created including a project for public relation, conservation, and water quality monitoring publications.

5. CONCLUSION

MRC-WQI was used as a tool to assess and classify the water quality in Nong Han Lake. This tool was used for assessing the lake water for specific purposes such protection of aquatic life, human consumption, and agricultural use. It was found that the lake water was good for agricultural use and aquatic life as indicated by WQIag. However, the results of WQIal and WQIhi showed that water quality was of moderate quality in the community area whereas agricultural community area had a good water quality. The tools indicate that DO was low and had quite high COD (near the community area) due to domestic wastewater discharge. Therefore, water management in Nhong Han should consider pollution prevention, environmental conservation, and social awareness.

ACKNOWLEDGEMENT

The authors are indebted to Nhong Han Development for Sustainable Livability Project and Kasetsart University Chalermphrakiat Sakon Nakhon Province Campus for financial support.

REFERENCES

[1] Suttibak, S. 2011. Study of water quality in Nhong Han Lake and pollution source: A case of nitrate and phosphate and impact from Nhong Han Lake utilization. In *Proceeding of 6th THAICID National Symposium "Integrated Water Resource Management towards Food Security and Sustainability".* Nonthaburi, Thailand 21 June.

[2] Pollution Control Department. (2011). WQI calculation [on-line]. Retrieved July 15, 2016 from theWorld Wide Web: http://iwis.pcd.go.th/officer/document/download/2/2.pdf

[3] Pollution Control Department. (1994). Surface Water Standard [online]. Retrieved July 15, 2016 from the World Wide Web: http://www.pcd.go.th/download/en_regulation.cfm?task=s3

[4] Boyacioglu, H;. and Boyacioglu, H. 2007. Surface water quality assessment by environmetric method. *Environmental Monitoring and Assessment* 131(1-3):371-376

[5] Dwivedi, S.L.; and Pathak, V. 2007. A preliminary assignmen of waer quality index to Mandakini River, Chitrakoot. *Indian Journal of Environmental Protection* 27(11):1036-1038

[6] Nasirian, M. 2007. A new water quality index for environmental contamination contributed by mineral processing: A case study of Amang (Tin Tailing) processing activity. *Journal of applied sciences* 7(20):2977-2987

[7] Bordolo, A.A.; Teixeira, R.; and Wiebe, W.J. 2006. A water quality index applied to an international shared river basin: The Case of Douro River. *Environmental Management 38*(6):910-920

[8] Alobaidy, A.H.M.J.; Abid, H.S. and Maulood, B.K. 2010. Application of water quality index for assessment of Donkan Lake ecosystem, Kurdistan Region, Iraq. *Journal of Water Resource and Protection* 2:792-798

[9] Akkoyunlu, A.; and Akiner, M.E. 2012. Pollution evaluation in streams using water quality indices: Acase study from Turkey's Sapanca Lake Basin. *Ecological Indicators* 18:501-511

[10] Sun, W.; Xia, C.; Xu, M.; Guo, J.; and Sun, G. 2016. Application of modified water quality indices as indicators to assess the spatial and temporal trends of water quality in the Dongjiang River. *Ecological Indicators* 66:306-312.

[11] Ly, K.; Larsen, K.; and Duyen, N. (2013). 2013 Lower Mekong Regional Water Quality Monitoring Report (MRC Technical Paper No. 51). Mekong River Commission, Vientiane

[12] APHA, AWWA, WEF. 2005. Standard methods for the examination of water and wastewater, 21st ed. Washington

[13] Canadian Council of Ministers of the Environment. (2001). Canadian water quality guidelines for the protection of aquatic life:CCME water quality index 1.0 (Report in : Canadian environmental quality guidelines, 1999). Canadian Council of Ministers of the Environment, Winnipeg.

[14] 9th Regional Environment Office. (2015). Environmental Quality Situation report 2015. (ISBN 974-286-154-4). 9th Regional Environment Office, Udonthani.