J. Environ. Res. 34(2) (2012): 89-106

ASSESSMENT OF SURFACE WATER QUALITY PARAMETERS AND THEIR VARIATIONS FOR EFFECTIVE RIVER MONITORING SYSTEM: A CASE STUDY OF U-TAPAO RIVER BASIN

การประเมินคุณภาพน้ำผิวดินและความแปรปรวนสำหรับระบบการตรวจวัดที่มีประสิทธิผล: กรณีศึกษาลุ่มน้ำอู่ตะเภา

Saroj Gyawali[1], Kuaanan Techato[1*], Chumpol Yuangyai[2] and Sathaporn Monprapussorn[3]

[1] Faculty of Environmental Management, Prince of Songkla University, Hatyai, Songkhla 90112, Thailand

[2] Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand

[3] Faculty of Social Science, Srinakharinwirot University, Bangkok 10110, Thailand

สาโรจ กยาวาลี[1] เกื้ออนันต์ เตชะโต[1*] ชุมพล ยวงใย[2] และ สถาพร มนต์ประภัสสร[3]

[1] คณะการจัดการสิ่งแวดล้อม มหาวิทยาลัยสงขลานครินทร์, สงขลา 90112 ประเทศไทย

[2] คณะวิศวกรรมศาสตร์ สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหาร ลาดกระบัง, กรุงเทพมหานคร 10520 ประเทศไทย

[3] คณะสังคมศาสตร์ มหาวิทยาลัยศรีนครินทรวิโรฒ, กรุงเทพมหานคร 10110 ประเทศไทย

received : August 14, 2012 accepted : October 5, 2012

Abstract

Water pollution has become an alarming threat to human society and natural ecosystems. Evaluation of water quality and its variations is essential for water quality management. This study aimed to analyze the spatial and temporal variations of water quality parameters and their interrelationship to support the current water quality monitoring system of U-tapao river. The data of physico-chemical and biological parameters namely: temperature, pH, electrical conductivity, suspended solid, turbidity, biological oxygen demand, dissolved oxygen, ammonia, and fecal coliform bacteria were collected from twenty-one monitoring stations of the basin from year 2004 to 2011. Analysis of variance, correlation analysis, and principal component analysis were used to find the variations and interrelationship of water quality parameters and sources of pollution of river, respectively. Temperature and dissolved oxygen showed significant variation both on spatial and annual level. Temperature, turbidity, fecal coliform bacteria, and ammonia showed significant seasonal variation. In addition, temperature had significant positive correlation with biological oxygen demand but significant negative correlation with dissolved oxygen. Dissolved oxygen had significant positive

* corresponding author
E-mail : uhugua@hotmail.com
Phone : +66-8-1841-8962

correlation with pH but significant negative correlation with biological oxygen demand, suspended solid and ammonia. From the principal component analysis, organic pollutant came from agricultural, household and industrial sectors whereas nutrient pollutant came from agricultural based activities. Therefore, analysis of water quality parameters revealed that U-tapao river is relatively polluted and needs monitoring to effectively solve the pollution problems. For effective river monitoring systems, knowledge of variations of water quality parameters and their interrelationship could be used to identify and mitigate the pollution of the river.

Keywords: pollution, river basin, spatial and temporal variation, correlation analysis, principal component/factor analysis and water quality

บทคัดย่อ

มลภาวะทางน้ำเป็นสัญญาอันตรายสำหรับคนและระบบนิเวศน์ การวัดคุณภาพน้ำและการแปรปรวนของคุณภาพน้ำเป็นสิ่งที่จำเป็นสำหรับการจัดการคุณภาพน้ำ การศึกษานี้จะวิเคราะห์การเปลี่ยนแปลงเชิงพื้นที่และเวลา รวมถึงความสัมพันธ์เพื่อสนับสนุนการตรวจวัดคุณภาพน้ำในแม่น้ำอู่ตะเภา ข้อมูลทางกายภาพ เคมี และชีวภาพ ได้แก่ อุณหภูมิ พีเอช ค่าการนำไฟฟ้า ปริมาณสารแขวนลอย ความขุ่น บีโอดี ดีโอ แอมโมเนีย และแบคทีเรียฟีคอลโคลีฟอร์ม ถูกรวบรวมจาก 21 สถานีตรวจวัดตั้งแต่ปี 2547 ถึง 2554 การวิเคราะห์ความแปรปรวน การวิเคราะห์ความสัมพันธ์ และการวิเคราะห์องค์ประกอบหลัก ถูกใช้หาความผันแปรของคุณภาพน้ำในระดับต่าง ๆ จากผลการศึกษาพบว่าอุณหภูมิและดีโอมีการเปลี่ยนแปลงตามพื้นที่และเวลาอย่างชัดเจน สำหรับอุณหภูมิ ความขุ่น แบคทีเรียฟีคอลโคลีฟอร์มและแอมโมเนียมีความแตกต่างในแต่ละฤดู นอกจากนี้อุณหภูมิมีความสัมพันธ์เชิงบวกกับบีโอดี แต่มีความสัมพันธ์เชิงลบกับดีโอ ในขณะที่ดีโอก็มีความสัมพันธ์เชิงบวกกับพีเอชแต่เป็นเชิงลบกับบีโอดี ปริมาณสารแขวนลอยและแอมโมเนีย จากการวิเคราะห์โดย principal component/factor มลพิษประเภทสารอินทรีย์มากจากการเกษตร บ้านเรือนและภาคอุตสาหกรรม ในขณะที่มลพิษประเภทที่เป็นสารอาหารได้จะเกิดจากกิจกรรมทางการเกษตร โดยภาพรวม แม่น้ำอู่ตะเภาจำเป็นต้องได้รับการแก้ไข ด้านการตรวจวัด ความรู้ด้านการศึกษาความแปรปรวนและความสัมพันธ์ต่าง ๆ เพื่อสามารถใช้อธิบายปัญหาของแม่น้ำได้

คำสำคัญ : มลภาวะ, ลุ่มน้ำ, ความแปรปรวนเชิงพื้นที่และเวลา, การวิเคราะห์ความสัมพันธ์, การวิเคราะห์องค์ประกอบหลัก และคุณภาพน้ำ

Introduction

Rivers, one of the most valuable natural resources on the earth, have been utilized by mankind for domestic and agricultural purposes for thousands of years with only few of them being in their natural conditions[1] .With rapidly growing urbanization and industrialization, different activities like unplanned construction and encroachment, clearing of riparian vegetation along the banks, disposal of waste materials, and unwise mining activities on the rivers are seriously degrading river's ecological system[2-3]. For this reason, they should be monitored on a regular basis to control pollution. Moreover, effective long term monitoring system of rivers requires fundamental understanding of various types of water quality parameters, their characteristics, and variations on different levels or scales[4].

Like other river systems, U-tapao river has been polluted from point and non point sources. From last decade, under continuous economic and social developments, natural resources and environment in the U-tapao river basin have been affected significantly. To meet the social and economic needs of people, the land use structure of basin has been changing dramatically. For example, paddy field and dry farming land have been converted into residential and industrial lands. The forest and agricultural areas have been converted mainly into large scale rubber plantation and human settlements. These changes have negatively impacted on the ecological integrity and hydrologic processes in the river system [5]. In the basin, most of the industries are located along the bank of U-tapao river which routinely discharge their waste directly into river without any treatment. Industrial waste is the most common point source pollution and generally comes from wet nature industries which require large quantities of water for processing and disposing wastes[6]. Even though agriculture is dominating land use structure of the basin, the most of agriculture based farming practices like shrimp and pig farming are located near the sides of river which are contributing a large scale of organic based pollution in the river system[7]. Besides, agriculture and industrialization, urbanization is another problem of the basin. In the last 30 years, urban development in this area has grown tremendously, especially along the lower section where the cities of Hatyai and Songkhla have grown and developed [5].

Consequently, the water quality of U-tapao river is affected from various natural as well as anthropogenic activities in the basin. To curb this problem, at first, effective monitoring system should be established in river network to ensure that the water quality is being maintained or restored at desired level. Water quality monitoring helps in evaluating the nature and extent of pollution control required, and effectiveness of pollution control measures that are already in existence. There are currently several organizations and agencies are involved to monitor water quality of river at different parts of Thailand. In the case of U-tapao river, Environmental Office-16, Songkhla is authentic and reliable monitoring agency of southern part of Thailand which has been collecting water quality data from 21 monitoring stations of U-tapao river on monthly basis. Due to lack of sophisticated tools and analytical skills, the monitoring agency has been facing many problems during collecting, presenting, and reporting the data on water quality. This study tried to solve some problems of existing monitoring system by implementing statistical analytical tools. Effective long term monitoring system of rivers requires a fundamental understanding of various types of water quality parameters and their characteristics and variations on different levels or scales [4]. Therefore, the objectives of this study are to find out the status of river by using descriptive statistics, interrelationships of various water quality parameters by using correlation analysis and variations on spatial and temporal level by using analysis of variance method. The results of this study would help understand the current monitoring system of U-tapao river and recommend further improvement if required.

Materials and Methods

Study area

U-tapao is a sub-basin of Songkhla lake basin which is located at southern part of Thailand. The basin is about 60 km long from north to south, and 40 km wide from west to east, and total coverage being about 2,305 km^2. The longitude and latitude of basin is 100º 10’ through 100º 37’ E and 6º 28’ through 7º 10’ N, respectively (Figure.1). The most dominating land use of the basin is agriculture which covers around 70% land of the basin. Forest land covers around 13% land of the basin whereas urban land covers around 9% and the remaining 8% land is covered by other land uses like water body, mining, grass and shrub etc. U-tapao river is one of the most important rivers of Songkhla lake basin which originates from Bantad Mountain and flows through Hatyai municipality before emptying into the outer part of Songkhla lake. The river has 10 tributaries including major and minor ones. During its course of 90 km, it receives a pollution load from both point and non-point sources. The main commercial city, Hatyai is located in midstream region whereas traditional city, Songkhla is located in downstream region of the basin [5].

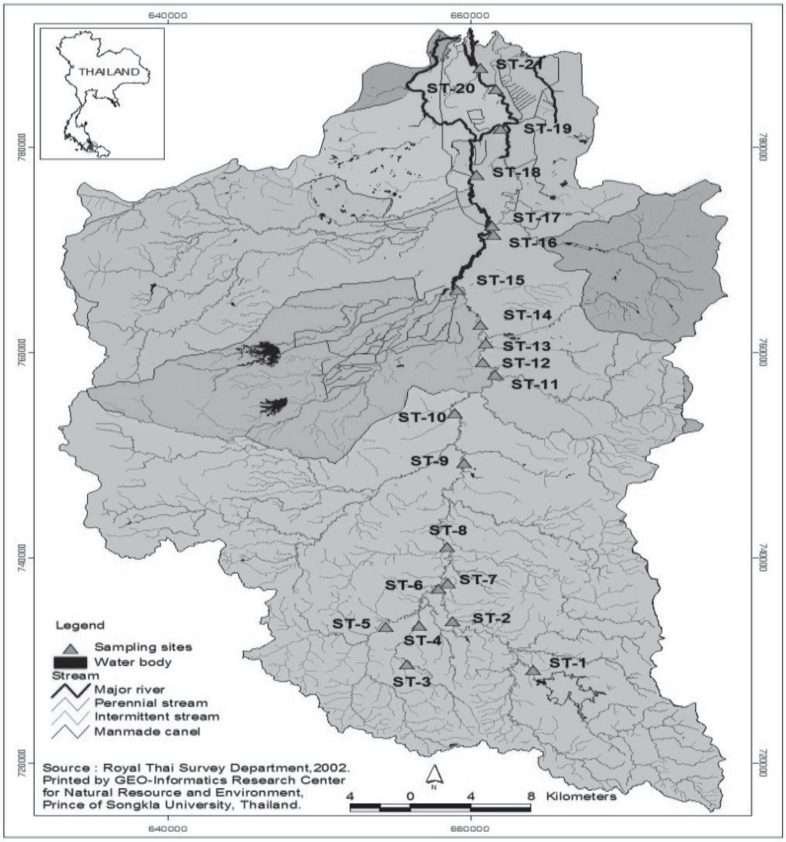

Figure 1 U-tapao river basin and 21 monitoring stations along the river

Data and methods

Secondary water quality monthly data (2004 – 2011) were collected from existing monitoring framework done by the Regional Environment Office 16, Songkhla. Water quality monitoring stations were located at 21 sites throughout the U-tapao river basin (Figure 1).

In this study, stations ST-1 to ST-9 represent upstream region of basin and the most of these areas were less affected from human activities. Stations ST-10 to ST-17 represent midstream region of basin and these areas were affected by almost all types of pollution from residential, agricultural, and industrial activities. Most of rubber processing and agricultural based industries are located along the stations ST-12 to ST-17. Stations ST-18 to ST-21 represent downstream region of basin and these regions were very much affected by agricultural, as well as shrimp and pig farming activities. Overall, most of the industries (more than 80%) were located on the banks of river, 10.1% industries were located in the upstream, 65% were located in the midstream and 24.9% were located in the downstream region.

The water quality parameters (WQP) for this study were temperature (TEMP), pH, biological oxygen demand (BOD), dissolved oxygen (DO), electrical conductivity (EC), suspended solid (SS), turbidity (TUR), fecal coliform bacteria (FCB), and ammonia (NH_3). For seasonal variation analysis, all data were divided into two categories: i) dry season (February, March, April and May) and ii) wet season (June, July, August, September, October, November, December, and January). Descriptive statistics were used to analyze the basic characteristics of water quality parameters and t-test was performed to analyze the seasonal variation of different water quality parameters. Pearson correlation analysis was used to find the interrelationship of water quality parameters. To analyze the variations of water quality parameters, one-way analysis of variance (ANOVA) was used to test whether spatial (sites) and annual fluctuations had any significant effect on the physico-chemical qualities of the river water. Principal component analysis was used to identify the sources of pollutation. The 5% level of significance (or 95% confidence interval) was set for entire study.

Results and Discussions

Results

General characteristics of water quality of U-tapao river were analyzed by descriptive statistics utilizing water quality data obtained from 21 monitoring stations from the year 2004 to 2011. The water quality data of U-tapao river for 9 parameters with their minimum, maximum, mean, and standard deviation among twenty one different stations and Thailand surface water quality standard (Pollution control) [8] are summarized in Table 1.

Table 1 Minimum, Maximum, Mean and Standard deviation of water quality parameters of U-tapao river from year 2004 to 2011

WQP	Mean	SD	Min	Max	Thailand's Surface water quality standard				
					Class 1	Class 2	Class 3	Class 4	Class 5
TEMP (ºC)	28.98	1.75	25.1	34.3	N	N'	N'	N'	-
pH	6.87	0.92	2.91	12.57	N	5-9	5-9	5-9	-
BOD (mg/L)	3.65	2.47	0.93	16.23	N	<1.5	1.5-2.0	2.0-4.0	-
DO (mg/L)	4.08	1.38	0.81	11.24	N	>6.0	4.0-6.0	2.0-4.0	-
EC (μs/cm)	765.70	1379.03	24	52800	-	-	-	-	-
SS (mg/L)	43.40	42.05	2	189	-	-	-	-	-
TUR (NTU)	50.91	53.97	3.00	319.00	-	-	-	-	-
FCB (MPN/100ml)	18640	56049	1300	500000	N	<1000	1000-4000	>4000	-
NH_3 (mg/L)	0.63	1.13	0.01	6.84	N	<0.5	<0.5	<0.5	-

N-naturally N' – naturally but changing not more than 3 ^{0}C

General statistics of water quality parameters on different monitoring stations

Temperature (TEMP): The mean temperature of U-tapao river was 28.98^{0}C. The highest temperature (34.3 ºC) was recorded during dry season on ST-17 which was located at midstream region of the basin and this region was highly polluted due to the discharged chemical and hot water effluents from neighboring industries. The lowest temperature (25.10ºC) was recorded during wet season on ST-2 which was located in upstream region of the basin and most part of this region was covered with natural vegetation. Overall, most of the stations (87.1%) showed the temperature less than 30 ºC.

pH: The mean pH value of surface water was 6.87. The highest pH value (12.57) was during wet season on ST-14 which was located at midstream region of the basin and the water quality of this region was also affected from anthropogenic activities. The lowest pH value (2.91) was during dry season on ST-18 which was located in downstream region of the basin. Average pH value of most of the stations (71.4%) was less than 7 but within the range of 6.5 to 7 which indicates the normal pH value of river system.

Dissolved oxygen (DO): The mean DO was 4.08 mg/L with the highest value (11.24 mg/L) was during wet season on ST-2 which was located at upstream region of the basin. The lowest value (0.81) was recorded during dry season on ST-14 which was located at midstream region of the basin. Average DO value of 81%

monitoring stations showed within the range 4.0 mg/L to 6.0 mg/L whereas 19% monitoring stations showed within the range 2.0 mg/L to 4.0 mg/L. Overall average value of DO was 4.08 mg/L which indicates the moderately polluted river system.

Biological oxygen demand (BOD): The mean BOD was 3.65 mg/L with the highest value (16.23 mg/L) was during dry season on ST-16, which was located in midstream region of the basin and the water quality of this region was polluted due to run-off drainage from nearby farmlands. The lowest value (0.93 mg/L) was recorded during wet season on ST-1, which was located upstream region of the basin and the water quality of this region is not so much polluted due to presence of natural vegetation. Average BOD of 85.7% stations was within the range 2mg/L to 4mg/L and 14.3% stations was more than 4 mg/L. But, overall average value of BOD was 3.65 mg/L which also indicates moderately polluted river system.

Fecal coliform bacteria (FCB): The mean FCB was 18,640 MPN/100ml with the highest FCB was on ST-15 which was located at midstream region and the water quality of this region was also polluted from human based activities. The lowest value was in ST-2 which was located in upstream region of the basin. In the basin, the average value of FCB of 23.8 % stations was within the range between 1000 MPN/100ml to 4,000 MPN/100ml and 76.2% stations was more than 4,000 MPN/100ml which also indicates the moderately polluted river system.

Correlation analysis of water quality parameters

In the study, the correlation analysis of the water quality parameters was performed from the secondary monthly data of 21 monitoring stations from the year 2004 to 2011. Water quality parameters showed the relationship among each other. TEMP had significant positive correlation with BOD and significant negative correlation with DO ($r = 0.325$, $p < 0.05$ & $r = -0.412$, $p < 0.05$). In this study, DO showed an expected inverse correlation to temperature as warmer surface water is known to have less DO due to oxygen saturation. As TEMP increases the saturation level of dissolved oxygen in water which yields an inverse correlation between these two parameters [4]. For pH, there was only significant positive correlation with DO ($r = 0.378$, $p < 0.05$) since increasing pH means decreasing the acidity level of water. BOD had significant negative correlation with DO ($r= -0.282$, $p<0.05$) and significant positive correlation with NH_3($r=0.335$, $p<0.05$) Generally, BOD has been used as an indirect measure of organic matter concentration in surface water, and in general it is negatively correlated with DO [9]. BOD is mainly determined by the concentration of organic matter, the amount BOD in water body is increased by nitrification process [10]. The important aspect of the result of this study is that DO showed negative correlation with TEMP, BOD, SS and NH_3 and positive correlation with pH (Table 2). Therefore, DO can be used an important indicator of explaining water quality status of river. Correlation analysis can be utilized to test the validity and reliability of data as well. For example, in this study, TEMP had significant positive correlation with BOD, BOD had significant positive correlation with NH_3, and SS had significant positive correlation with TUR. Therefore, the water quality data collected from different monitoring stations were reliable and valid (Table 2).

Table 2 Correlation analysis table of water quality parameters of U-tapao river basin (2004-2011)

WQP	TEMP	pH	BOD	DO	EC	SS	TUR	FCB	NH_3
TEMP	1								
pH	0.021	1							
BOD	**0.325***	-0.045	1						
DO	**-0.412***	**0.378***	**-0.282***	1					
EC	0.022	0.053	0.113	-0.061	1				
SS	-0.017	0.091	0.211	**-0.212***	-0.001	1			
TUR	-0.134	0.011	0.003	0.001	0.013	**0.496***	1		
FCB	0.136	-0.072	0.132	-0.091	-0.066	0.033	0.131	1	
NH_3	0.061	-0.031	**0.335***	**-0.371***	-0.011	-0.137	-0.072	**0.392***	1

* $p<0.05$

Variations of water quality parameters

In this study, TEMP clearly showed variation on spatial, annual, and season level. There was a significant difference on mean values of water temperature on spatial level ($F= 8.390$, $p<0.05$) (Table 3) and annual level ($F= 15.304$, $p <0.05$) (Table 4); and temperature was significantly higher during dry season compared to wet season ($t = 5.491$, $p<0.05$) (Table 5). About pH, there was no significant difference on mean pH values on spatial level but there was a significant difference on annual level ($F = 16.734$, $p <0.05$). EC showed a significant difference on mean values on annual level ($F = 23.841$, $p < 0.05$) but not on spatial and seasonal levels. BOD showed a significant difference on mean values of on annual level ($F = 7.437$, $p < 0.05$) but not on spatial and seasonal levels DO showed a significant difference on mean values on annual and spatial level ($F = 19.116$, $p < 0.05$ & $F = 11.898$, $p < 0.05$) but not on seasonal level. There was no significant variation on mean values of SS on annual, spatial and season levels. FCB value was higher during dry season compared to wet season ($t = 2.053$, $p < 0.05$). NH_3 showed significant difference on mean values on annual and season levels ($F = 13.468$, $p < 0.05$ & $t = 2.709$, $p < 0.05$) but not on spatial level.

Table 3 Mean and Standard deviation of water quality parameters of 21 monitoring stations and F-ratio

		TEMP	pH	EC	TUR	BOD	DO	SS	FCB	NH_3
ST-1	Mean	27.86	6.89	92.61	28.86	2.46	5.76	23.20	5443	0.056
	SD	1.37	0.64	17.16	39.98	3.09	1.23	12.05	9142	0.047
ST-2	Mean	27.48	6.92	41.19	33.13	2.31	5.63	17.02	2096	0.026
	SD	1.16	0.94	16.17	32.18	2.14	0.95	9.34	1258	0.026
ST-3	Mean	28.48	7.18	723.62	9.13	3.86	4.09	17.34	7900	0.150
	SD	1.39	0.58	937.19	3.87	1.88	1.54	14.98	8143	0.116
ST-4	Mean	27.91	6.93	202.93	1.83	2.72	4.68	25.07	2400	0.196
	SD	1.11	0.71	215.54	4.68	1.25	1.57	23.95	1200	0.226
ST-5	Mean	27.52	6.67	110.50	28.93	3.45	4.04	27.41	21866	0.156
	SD	1.17	0.65	44.30	23.47	1.38	0.95	22.54	28035	0.179
ST-6	Mean	28.17	6.75	111.86	3.12	4.12	4.05	27.95	3133	0.214
	SD	1.44	0.64	63.36	10.94	2.84	1.58	15.64	1985	0.232
ST-7	Mean	28.14	6.55	103.63	25.16	3.01	4.81	32.81	1993	0.172
	SD	1.25	0.77	51.02	10.55	2.30	1.02	31.29	1069	0.247
ST-8	Mean	28.49	6.76	107.87	33.30	3.13	4.68	54.91	2100	0.122
	SD	1.33	0.53	75.66	6.54	0.87	1.18	31.96	1248	0.115
ST-9	Mean	28.72	6.98	94.68	48.36	3.07	4.63	72.83	5366	0.02
	SD	1.33	0.78	51.29	36.10	0.98	0.53	49.63	92093	0.031
ST-10	Mean	28.91	6.89	97.06	41.23	2.67	4.99	92.60	4343	0.072
	SD	1.51	0.67	50.93	22.20	0.69	0.58	55.73	4499	0.008
ST-11	Mean	29.24	6.85	152.68	40.70	3.30	4.62	174.82	8966	0.073
	SD	1.57	0.59	73.31	27.98	1.24	0.67	59.92	7152	0.078

Table 3 Mean and Standard deviation of water quality parameters of 21 monitoring stations and F-ratio

		TEMP	pH	EC	TUR	BOD	DO	SS	FCB	NH_3
ST-12	Mean	29.07	6.73	161.18	39.20	3.40	4.34	167.38	54700	0.108
	SD	1.47	0.74	78.40	26.62	1.37	0.83	36.55	91193	0.095
ST-13	Mean	29.20	6.95	233.43	37.10	3.72	3.96	133.43	13733	0.094
	SD	1.70	0.70	199.19	20.26	1.48	0.70	36.34	3989	0.063
ST-14	Mean	29.05	7.11	175.55	39.66	3.99	3.77	134.23	13703	0.092
	SD	1.69	1.44	60.91	19.73	3.62	0.74	22.37	3925	0.084
ST-15	Mean	29.22	7.08	168.50	43.06	4.03	3.82	76.43	56563	0.136
	SD	1.81	1.46	64.27	20.97	2.55	0.73	37.38	89684	0.120
ST-16	Mean	29.38	6.83	1402.28	65.81	4.10	3.59	45.94	4405	1.206
	SD	1.91	0.77	7680.68	74.01	3.08	1.07	44.82	7873	1.709
ST-17	Mean	30.12	7.08	232.95	41.06	3.73	4.18	32.45	7203	0.097
	SD	1.96	1.46	298.53	19.30	2.10	1.74	23.34	8047	0.158
ST-18	Mean	29.55	6.75	1300	79.11	4.57	3.32	46.34	53094	0.891
	SD	1.63	1.14	6866.33	75.78	2.58	0.99	44.32	117749	0.949
ST-19	Mean	30.72	7.20	954.25	37.93	3.72	3.53	27.34	9303	0.233
	SD	1.60	0.81	1783.39	25.74	1.67	1.33	36.56	6601	0.204
ST-20	Mean	29.79	6.66	3094.15	59.95	3.87	2.93	76.41	8271	1.302
	SD	1.60	1.07	9101.76	60.09	2.15	1.29	28.45	9252	1.540
ST-21	Mean	30.37	7.00	2790.95	27.16	4.37	2.98	63.32	7243	0.126
	SD	1.23	1.07	5110	19.67	3.34	1.47	21.21	7995	0.141
F ratio		8.390	0.896	1.262	0.655	1.219	11.898	2.745	0.436	0.686
P		0.001	0.59	0.200	0.858	0.236	0.001	0.073	0.981	0.829

Table 4 Mean and Standard deviation of water quality parameters from year 2004 to 2011 and F-ratio

		TEMP	pH	EC	TUR	BOD	DO	SS	FCB	NH_3
2004	Mean	28.94	7.23	34.67	84.22	4.66	4.24	64.91	9602	1.94
	SD	2.19	0.62	51.65	56.98	3.43	1.13	21.96	7713	2.74
2005	Mean	29.64	6.68	2166.55	115.16	4.56	3.35	72.31	26201	0.983
	SD	1.72	0.25	5752.41	139.13	3.29	0.57	59.61	50829	0.743
2006	Mean	29.36	5.82	77.05	48.09	3.58	3.48	62.61	62966	0.59
	SD	1.01	0.75	70.63	27.96	1.95	0.87	45.72	164180	0.186
2007	Mean	28.93	6.15	159993.33	66.60	5.47	2.63	44.82	12630	0.932
	SD	1.85	1.05	23844.51	55.08	3.89	0.37	59.99	25510	0.418
2008	Mean	28.05	6.98	135.35	57.30	3.08	3.60	44.91	18640	2.20
	SD	1.34	1.24	53.80	24.65	1.63	1.37	31.93	56049	1.48
2009	Mean	28.18	6.56	187.84	50.01	3.01	4.54	52.83	13560	0.659
	SD	1.23	0.53	595.80	53.97	1.11	1.44	49.64	78300	0.217
2010	Mean	29.83	7.28	732.21	54.02	3.61	4.41	42.60	27531	0.162
	SD	1.76	0.76	2306.07	51.38	1.86	1.14	34.73	58754	0.738
2011	Mean	28.78	6.78	323.57	34.30	3.02	4.55	46.82	15327	0.125
	SD	1.60	0.58	901.48	21.41	2.04	1.29	39.97	34031	0.129
F ratio		15.304	16.734	23.841	5.589	7.437	19.116	1.949	1.403	13.468
P		0.001	0.001	0.001	0.001	0.001	0.001	0.397	0.230	0.001

Table 5 Mean and Standard deviation of water quality parameters of two seasons and t-value

Season		TEMP	pH	EC	TUR	BOD	DO	SS	FCB	NH_3
Dry	Mean	29.47	6.84	495.15	35.23	3.81	4.18	34.01	6444	0.303
	SD	1.18	0.78	1710.11	21.42	2.63	1.43	28.93	6837	0.448
Wet	Mean	28.63	6.89	959.42	63.45	3.51	4.02	44.84	28396	0.888
	SD	1.63	1.01	5310.21	67.50	2.30	1.33	43.83	73771	1.40
	|t|	5.491	0.572	1.160	2.784	1.117	1.255	0.583	2.053	2.709
	p	0.001	0.568	0.247	0.006	0.265	0.210	0.563	0.043	0.008

Principal component analysis

Principal component analysis was performed on the normalized data set of 9 water quality variables. Eigen values of 1.0 or greater than 1.0 were considered significant values for analysis and factor values >0.75, 0.75-0.50, and 0.50-0.0 were explained as strong, moderate, and weak loading respectively and only strong factors were considered for analysis [(4)]. In this study, 70.78% of total variation was explained for data set of water quality parameters (Table 6). For the data set of water quality parameters, among four VFs, VF1 which explained 25.09% of total variance had strong positive loading on TUR which explained the erosion from upland areas and surface runoff from agricultural and urban areas. In the basin, the most dominating land use is agricultural land which covers around 70% of total land of the basin and urban land covers around only 9% of the basin. Due to urbanization and industrialization process in the basin, most of the agricultural land being converted to urban land which increases surface runoff and that is very much related to TUR of water quality. VF2, which explained 18.70% of total variance, had strong positive loading on NH_3. This factor explained the pollution from agricultural and household activities. In the basin, most farmers use chemical fertilizers in their field which might increase the concentration of ammonia in river system. Because Hatyai and Songkhla are two major cities of the basin, the household and industrial waste from these cities also might increase the level of nutrients in the river system. VF3, which explained 14.94% of total variance, had strong positive loading on EC which explains the pollution related to industrial activities. VF4, which explained 12.05% of total variance, had strong positive loading on BOD which explains the organic pollution from agricultural and household activities. Most of the upper part of basin is covered with rubber tress where human activities like agricultural practices, industrialization and urbanization are much profound in the downstream region of the basin. These activities definitely increase the organic pollution which may explain the strong positive loading of BOD in the river system.

Table 6 Loading of 9 water quality variables on principal component analysis

Parameters	VF1	VF2	VF3	VF4
TEMP	-0.498	-0.141	-0.390	0.309
pH	-0.061	0.027	0.217	-0.295
BOD	-0.265	0.527	0.320	0.751
DO	-0.060	-0.388	-0.016	0.055
EC	0.125	-0.046	0.987	-0.085
SS	0.511	-0.118	0.020	-0.141
TUR	0.996	0.023	-0.007	0.086
FCB	-0.077	-0.101	-0.045	0.251
NH_3	-0.214	0.957	-0.066	-0.022
Eigen value	2.258	1.683	1.344	1.083
%Total variance	25.09	18.70	14.94	12.05
%Cumulative variance	25.09	43.79	58.73	70.78

Discussions

Analyzing the spatial and annual variations of water quality parameters of U-tapao river, TEMP and DO showed significant variation on spatial level whereas pH, EC, TUR, BOD, and NH_3 showed significant variation only on annual level. Such variations could be attributed to the increased input of industrial effluents from the local industries sites along the banks of the river, leached domestic wastes from several waste dumps, erosion and surface run-offs and other human activities with progressive downstream of the river[2]. Generally, both annual and spatial variations are related to anthropogenic activities [3]. But, most of the water quality parameters showed annual variation rather than spatial variation. It is due to the fact that the changing pattern of land use of the basin does not concentrate at a particular location but it has simultaneously affects the entire basin with time.

In case of variation analysis of water quality parameters, previous studies included only spatial and seasonal variations for analysis of water quality parameters [11]. Excluding annual variation might give misleading information about variations of water quality parameters. Therefore, this study added annual variation to better understand the river water quality variation. Comparison of annual and spatial variation revealed that most of the parameters vary on annual level rather than on spatial level. Therefore, it is suggested to decrease monitoring sites of river since most of water quality parameters did not show any variation in spatial level. In contrast, most of water quality parameters showed variation in annual level. It is recommended continuing the current monthly evaluation system.

For the case of seasonal variation, only TEMP, TUR, FCB and NH_3 showed significant variation. Generally, seasonal variation is due to natural process whereas annual spatial variation is due to anthropogenic activities [4]. Among all types of variations, TEMP was the most sensitive parameter for variation analysis. During subgroup analysis of annual and spatial variations, TEMP and DO could be considered as sensitive parameters for measuring variations. Therefore, this type of understanding of variations of water quality parameters helps us to select appropriate parameters for effective evaluation and monitoring system of the river.

In the river monitoring system, the knowledge of interrelation of various water quality parameters could be used to test the reliability and validity of water quality of data[11]. Moreover, this knowledge can be used to predict the water quality parameters. In this study, some parameters showed significant correlation whereas some did not. TEMP showed significant positive correlation with BOD and negative correlation with DO and DO had positive correlation with pH and negative correlation with BOD, SS, and NH_3 which means higher values of pH and lower values of BOD, SS, and NH_3 is beneficial for maintaining good ecosystem of U-tapao river[12]. In this study, most parameters showed negative correlation with DO, implying that DO can give some ideas of the status of water quality in the U-tapao river. The higher degree of negative correlation between DO and BOD indicates the poor water quality of river system whereas the low degree of negative correlation indicates less polluted river system [4].

From principal component analysis, TUR showed higher positive loading which explains the pollution of river in terms of surface runoff from agricultural and urban areas and upland erosion[2]. Furthermore, it was worse during the wet season that might be due to erosion of soil carried by runoff from the catchment areas [4]. In addition, the increased levels of TUR are caused by sediments and other matters suspended in the water column[13] and abnormal values of TUR are usually due to discharge of water in the form of floating sediments carried by the river from catchment areas [14].NH_3 also showed higher positive loading explaining the pollution from agricultural and household activities of basin. Generally, level of NH_3 is attributed mainly to anthropogenic activities such as runoff water from agricultural lands, discharge of household and municipal sewage from the market place[15]. The concentration of NH_3 in the river plays vital role to maintain the aquatic environment of river and high value of NH_3 (p >0.5 mg/L) is not good for aquatic life[3]. In this study, EC showed higher positive loading which indicates pollution from industrial activities[13]. Most of industries around the basin are located on the bank of the river which might be the cause of industrial pollution increasing the value of EC. High loading of BOD also indicates organic pollution from agricultural and household activities[16].

Analyzing the water quality parameters of the U-tapao river, most of the parameters are somehow used to explain the variations and interrelation to each other. All the parameters except suspended solid were used to explain the variations either in spatial or temporal or seasonal levels. But, suspended solid was used to explain the interrelationship with turbidity. Due to this reason, it is not recommended to reduce the water quality parameters in this river monitoring system. Principal component analysis also did not indicate the reduction of parameters for monitoring system; it only explained 70.78% of variations from these parameters[16,17,18]. For complete understanding and improvement the water quality monitoring system, it is recommended to add extra indicators of nutrient pollution like nitrate, nitrite, total phosphorous and heavy metal pollution like zinc, lead, and cupper.

Conclusions

Based on the water quality parameters (dissolved oxygen, biological oxygen demand, and fecal coliform bacteria), U-tapao river could be regarded as moderately polluted river. Like other rivers, the quality of water is better in upstream regions rather than in downstream regions. The information obtained from the analysis of surface water quality along the river suggests that the level of pollution is not yet beyond control, but the effective control measures should be implemented for preventing further deterioration. If proper measures are taken for the treatment of sewage before discharge and restrictions are put on various anthropogenic activities upstream as well as downstream, the river would remain healthy in the long run.

From variation analysis, temperature can be used as the most sensitive parameter, since it showed significant variation on all levels. Dissolved oxygen is also sensitive for spatial and annual variations. Analyzing the data with respect to annual and spatial variations, most of the parameters showed variation on annual level rather than on spatial level. Therefore, it is recommended to reduce the monitoring sites of river. From correlation analysis, the knowledge of the interrelationships of various parameters could be used to test the reliability and validity of water quality of data and to predict the water quality parameters as well. From the principal component analysis, turbidity, ammonia, biological oxygen demand and electrical conductivity were identified as indicators of pollution sources of river. In sum, it is recommended to add extra water quality parameters for better understanding of river system.

These findings can be helpful to Environmental Office, Songkhla to select appropriate parameters and to draw basic features of U-tapao river and causes and consequences of variations of water quality parameters. It also provides a valuable tool in developing assessment strategies for effective water quality management and rapid solutions on pollution as well. Since this is the first kind of such research on U-tapao river, the results will be handful to expand future research by using multivariate statistical methods to find out spatial and temporal variations of water quality and to identify the core sources of pollution.

Acknowledgements

The authors are highly thankful to the staff of Environmental Office-16, Songkhla and GEO-Informatics Research Center for Natural Resource and Environment, Hatyai, Thailand for all the support provided for the study.

References

(1) Ngoye, E. and Machiwa, J.F. 2004. The influence of land-use patterns in the Ruvu river watershed on water quality in the river system. Phys. Chem. Earth. 29: 1161-1166.

(2) Adamu, M. and Nabegu A.B. 2011. Surface water pollution source identification using principal component and factor analysis in Getsi River, Kano, Nigeria. Aust. J. Basic Appl. Sci. 5(12): 1507-1512.

(3) Abdullahi, B.A., Kawa, A.H. and Naaliya, J. 2008. Observation on the seasonal and spatial variation water quality on the seasonal and spatial variation water quality and ecological implication of Challawa River Nigeria. Bioscience Research Communities. 20(3): 121-126.

(4) Shrestha, S. and Kazama, F. 2007. Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan. Environ. Model. Softw. 22(4): 464-474.

(5) Gyawali, S., Techato, K., Monprpussorn, S. and Yuangyai, C. 2011. Integrating land use and water quality for environmental based land use planning for U-tapao River Basin, Thailand. PSU-USM International Conference on Humanities and Social Science, Hatyai, Songkhla, Thailand, October, 3-4, 2011.

(6) Gyawali, S., Techato, K. and Yuangyai, C. 2012. Effects of industrial waste disposal on the surface water quality of U-tapao river, Thailand. International Conference on Environment

Science and Engineering (ICESE, 2012), Bangkok, Thailand, April 7-8, 2012.

(7) Gyawali, S. and Techato, K. 2011. The influence of agricultural land use on water quality of U-tapao river Thailand. The 2nd International Conference on Sustainable Future for Human Security –SUSTAIN 2011, Kyoto, Japan, October 8-9, 2011.

(8) Pollution Control Department. 1997. Water Quality Standards of Thailand, Water Quality and Management. Pollution Control Department, Ministry of Science and Technology, Bangkok.

(9) Ferrier, R.C., Edward, A.C., Hirst, D., Littlewood, I.G., Walts, C.D. and Morris, R. 2001. Water quality of Scottish rivers: spatial and temporal trends. Sci. Total Environ. 265: 327-342.

(10) Jain, S.K., and Singh, V.P. 2003. Water resources systems planning and management. Amsterdam: Elsevier.

(11) Ojutiku, R.O. and Kolo, J. 2011. Temporal and spatial variation of physcio-chemical parameters of river Chanchaga, Niger State, Nigeria. J. Appl. Biosci. 47: 3242-3255.

(12) Liu, C.W., Lin, K.H. and Kuo, Y.M. 2003. Application of factor analysis in the assessment of groundwater quality in a Blackfoot disease area in Taiwan. Sci. Total Environ. 313: 77-89.

(13) Bhatta, R.P. and Khanal, S. N. 2011. Impoundment after damming the rivers change in flow regime and effect in water quality of Chilime Hydropower project in Rasuwa District Nepal. Advances in Bioresearch. 2(1): 33-39.

(14) Milovanovic, M. 2007. Water quality assessment and determination of pollution sources along the Axios/Vardar River, Southeastern Europe. Desalination. 213: 159-173.

(15) Fakayode, S.O. 2005. Impact assessment of industrial effluent on water quality of the receiving Alaro River in Ibadan, Nigeria. Ajeamragee 10: 1-13.

(16) Raj, N. and. Azeez, P. A. 2009. Spatial and temporal variation in surface water chemistry of a tropical river, the river Bharathapuzha. Curr. Sci. India. 90: 245-251.

(17) Marofi, S. 2006. Temporal and spatital variability in streamwater quality in a catchment affected by waster water. Pak. J. Biol. Sci. 9: 985-990.

(18) Mustapha, A. and Nabegu, A. B. 2011. Surface water pollution source identification using principal component and factor analysis in Getsi River, Nigeriam. Aust. J. Basic Appl. Sci. 5(12): 1507-1512.