THE MONITORING AND ASSESSMENT OF WATER QUALITY IN THE UPPER PART OF CHI BASIN USING PHYSICOCHEMICAL VARIABLES AND BENTHIC MACROINVERTEBRATES

Nukool Kudthalang

A Thesis Submitted in Partial Fulfillment of the Requirements

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การตรวจสอบและประเมินคุณภาพน้ำในลุ่มน้ำชีตอนบนโดยใช้ปัจจัยทางเคมีกายภาพ และสัตว์ไม่มีกระดูกสันหลังหน้าดิน

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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นุกูล กุดแถลง : การตรวจสอบและประเมินคุณภาพน้ำในลุ่มน้ำชีตอนบนโดยใช้ปัจจัยทางเคมีกายภาพ และสัตว์ไม่มีกระดูกสันหลังหน้าดิน (THE MONITORING AND ASSESSMENT OF WATER QUALITY IN THE UPPER PART OF CHI BASIN USING PHYSICOCHEMICAL VARIABLES AND BENTHIC MACROINVERTEBRATES) อาจารย์ที่ปรึกษา : ผศ. ดร.ณัฐวุฒิ ธานี, 143 หน้า

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อติดตามตรวจสอบและประเมินคุณภาพน้ำในกลุ่มน้ำชีตอนบน โดยใช้ปัจจัยทางเคมีกายภาพและสัตว์ไม่มีกระดูกสันหลังหน้าดิน โดยเก็บตัวอย่างจาก 10 จุดศึกษาในลุ่มน้ำชีตอนบน การเก็บตัวอย่างทำการเก็บทุกๆ 2 เดือน โดยใช้สวิงรูปสี่เหลี่ยม ทำการศึกษาคุณภาพน้ำทางกายภาพและเคมีทั้งหมด 12 ตัวแปร ดัชนีชีวภาพที่ศึกษาได้แก่ BMWP^{Thai} ร่วมกับ ASPT ดัชนีความหลากหลายทางชีวภาพ และดัชนี HBI วิเคราะห์ความแปรปรวน และวิเคราะห์สหสัมพันธ์ เพื่อหาความสัมพันธ์ระหว่างปัจจัยต่างๆ ทั้งระหว่างจุดศึกษาเก็บตัวอย่าง และฤดูกาล ผลการศึกษาพบว่าคุณภาพน้ำสามารถแบ่งตามประเภทคุณภาพได้ 2 กลุ่ม คือ กลุ่มที่ 1 ได้แก่ จุดศึกษาที่ 1 จัดอยู่ในประเภทที่ 2 เป็นแหล่งน้ำที่ได้รับน้ำทิ้งจากกิจกรรมบางประเภทและสามารถใช้ประโยชน์เพื่อการอุปโภคและบริโภคโดยต้องผ่านการฆ่าเชื้อตามปกติและผ่านกระบวนการปรับปรุงคุณภาพน้ำทั่วไปก่อน การอนุรักษ์สัตว์น้ำ การประมง การว่ายน้ำ และกีฬาทางน้ำ กลุ่มที่ 2 ได้แก่ จุดศึกษาที่ 2 ถึงจุดศึกษาที่ 10 จัดอยู่ในประเภทที่ 3 เป็นแหล่งน้ำที่ได้รับน้ำทิ้งจากกิจกรรมบางประเภท และสามารถเป็นประโยชน์เพื่อการอุปโภคและบริโภคโดยต้องผ่านการฆ่าเชื้อตามปกติและผ่านกระบวนการปรับปรุงคุณภาพน้ำทั่วไปก่อน การเกษตร เมื่อเปรียบเทียบกับมาตรฐานคุณภาพน้ำในแหล่งน้ำผิวดิน สัตว์ไม่มีกระดูกสันหลังหน้าดินพบทั้งหมด 8 อันดับ 25 วงศ์ โดยอันดับที่พบมากที่สุดคือ Odonata และวงศ์ที่พบมากที่สุดคือ Gomphidae เมื่อประเมินคุณภาพน้ำโดยใช้ดัชนีชีวภาพพบว่าความหลากหลายทางชีวภาพของสัตว์ไม่มีกระดูกสันหลังหน้าดินจะไม่สอดคล้องกับการประเมินโดยใช้ปัจจัยทางเคมีกายภาพ ส่วนดัชนี BMWP^{Thai} ร่วมกับ ASPT และดัชนี HBI มีความสอดคล้องกับการประเมินโดยใช้ปัจจัยทางเคมีกายภาพ

สาขาวิชาชีววิทยา ลายมือชื่อนักศึกษา________________________

ปีการศึกษา 2549 ลายมือชื่ออาจารย์ที่ปรึกษา___________________

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม________________

NUKOOL KUDTHALANG : THE MONITORING AND ASSESSMENT OF WATER QUALITY IN THE UPPER PART OF CHI BASIN USING PHYSICOCHEMICAL VARIABLES AND BENTHIC MACROINVERTEBRATES. THESIS ADVISOR : ASST. PROF. NATHAWUT THANEE, Ph.D. 143 PP.

WATER QUAULITY / CHI BASIN / PHYSICOCHEMICAL VARIABLES / BENTHIC MACROINVERTEBRATES

The purpose of this research was to monitor and assess water quality using physicochemical measurements and benthic macroinvertebrates in the upper part of the Chi basin. Ten sampling sites were established along the river course. Physicochemical and biological properties were measured bimonthly. Twelve physicochemical variables of water quality were examined and analyzed. The benthic macroinvertebrates were collected by rectangular dip net - kicking sample from February to December 2004. Diversity index, BMWP^{Thai} score and ASPT and HBI index were used to assess water quality. Correlation between sampling sites and between seasons were analyzed by ANOVA. The results showed that the water quality of the upper part of the Chi basin were classified into 2 groups. Site 1 was classified in class 2 with very clean freshwater resources. Site 2 to 10 were classified in class 3 with medium clean freshwater resources. Benthic macroinvertebrates of 8 orders 25 families were found. The most abundant order was Odonata and the most abundant family was Gomphidae. The diversity index was used to assess the water quality. The values of diversity index did not agree with the water quality assessed

by physicochemical. On the other hand, the water quality assessed by HBI index and ASPT agreed with the water quality assessed by physicochemical analyses.

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Academic Year 2006 | Advisor's Signature________________________

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Nukool Kudthalang

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LIST OF ABBREVIATIONS

BI	=	Biotic Index
FBI	=	Family Biotic Index
HBI	=	Hillsenhoff Biotic Index
EPT	=	Ephemeroptera Plecoptera and Trichoptera
BMWP	=	the Biological Monitoring Working Party
ASPT	=	Average Score Taxon
BOD	=	Biochemical Oxygen Demand
DO	=	Dissolved Oxygen

CHAPTER I

INTRODUCTION

1.1 The Importance of Problems

The population of the world is increasing rapidly. Based on current rates of birth it is increasing by 1.5% per year (Pimental, www, 1998), or more than a quarter of a million people each day. It is obvious that the rapid growth puts enormous pressure on natural resources such as petroleum, forest, land, and freshwater. Furthermore, associated economic growth and technological development often associate with increasing air, water and soil pollution. Water is a basic necessity of life, not only for people but also for plants and animals. People use water for sanitation, agriculture, industry, urban development, hydro generation, inland fisheries, transportation, and recreation. Water is a renewable natural resource. The total amount of water on earth is around 1,400 million km^3. The volume of freshwater is about 2.5% or about 35 million km^3. Most of freshwater is found in permanent ice or snow such as that locked up in Antarctica and Greenland, or deep groundwater. The main sources of water for humans are lakes, rivers, soil moisture and relatively shallow groundwater basins. The usable portion of these sources is only about 2,000,000 km^3 of water - less than 1% of all freshwater and only 0.01% of all water on earth (UNEP, www, 2002). Therefore, protection, conservation and management of the freshwater resource is necessary for its sustainable use.

The Chi river is one of the most important main rivers in Northeastern Thailand. Approximately 7,100,000 people live close to it and depend on it for their water supply (ตามรอยต้นน้ำชี, www, 2544). The water is used inefficiently for agriculture, industry and consumption. The Chi river is polluted and water management is poor. The problem is caused by the poor management of water supplies. Therefore, the freshwater in the Chi river should be continually monitored for water quality. The scientific method can correctly identify the water quality. The researcher is interested in monitoring and assessing the water quality in the upper part of Chi river basin by using physicochemical measurement and benthic macroinvertebrates, as indicators.

1.2 Research Objectives

1.2.1 To monitor and assess water quality using physicochemical measurements and benthic macroinvertebrates in the upper part of Chi river basin.

1.2.2 To study type, diversity of benthic macroinvertebrates in the upper part of Chi river basin.

1.2.3 To examine the correlation between water quality and benthic macroinvertebrates in the upper part of Chi river basin.

1.3 Research Hypothesis

The water quality at different sites along the upper part of Chi river basin differ physicochemically in their of benthic marcroinvertebrates diversity and water quality affects the benthic macroinvertebrate communities.

1.4 Scope and Limitation This Study

1.4.1 The Scope of the Study Area

The upper part of Chi river basin is occupied by Chaiyaphum, Nakhon Ratchasima, Petchabun, Loei, Udon Thani, Nong Bua Lam Phu and Khon Kaen province. Ten sampling sites in the upper part of Chi river basin were chosen from Chiyaphum to Khon Kaen province.

1.4.2 The Scope of Contents

Benthic macroinvetebrates were collected from 10 sampling sites along the upper part of Chi River basin from Chaiyaphum to Khon Kaen province. The water quality was dissolved oxygen, electrical conductivity, pH, temperature, velocity, biochemical oxygen demand, phosphate, nitrate, turbidity, ammonia, hardness and alkalinity. Some parameters were measured at the sampling sites such as dissolved oxygen, electrical conductivity, pH, temperature and velocity. Others such as biochemical oxygen demand, phosphate, nitrate, turbidity, ammonia, hardness and alkalinity were analyzed in the science laboratories at Rajabhat Maha Sarakham University and Suranaree University of Technology.

1.4.3 The Period of Time

The water samples were collected and analyzed bimonthly from February 2004 – December 2004.

1.5 Expected Results

1.5.1 The correlation between water quality and benthic macroinvertebrates can be evaluated in the upper part of Chi river basin.

1.5.2 The results of this research will be useful for environmental planning and provide valuable information for watershed management.

1.6 Key Words: water quality, Chi river basin, physicochemical variables, benthic macroinvertebrates and monitoring

Water quality is a term used to express the suitability of water to sustain varies uses or processes (Meybeck, Kuusisto, Mäkelä and Mälkki, 1996 quoted inBatram and Balance, 1996).

Chi river basin is the area of upper part of Chi river basin about 29,525 km2.

Benthic macroinverbrates are animals inhabiting the substratum of lakes, stream, and estuarine water. Although very young specimens of many forms are small, macroinvertebrates are considered by definition to be visible the unaided eye and are retained on a US Standard No. 30 sieve (0.595 µm openings) (STANDARDMETHODS, www, 2001).

Physicochemical variables are relating to both physical and chemical properties of water quality.

Monitoring is the long - term standardized measurement and observation of the aquatic environment in order to define status and trends (Meybeck, Kuusisto, Mäkelä and Mälkki, 1996 quoted in Batram and Balance, 1996).

CHAPTER II

LITERATURE REVIEW

2.1 Study Area

The Chi river, of about 765 kilometer long is the longest river in Thailand. It is in the Northeast of Thailand and passes through 12 provinces. The twelve provinces occupy some parts of the Chi basin, they are Petchabun, Chaiyaphum, Nakhon Ratchasima, Loei, Udon Thani, Nong Bua Lam Phu, Khon Kaen, Maha Sarakham, Kalasin, Roi Et, Yasothon and Ubon Ratchathani. The Chi river originates in Pang Hoei mountain of the Petchabun range at 15° 30′ N, 104º 30′ E (ตามรอยต้นน้ำชี, www, 2544). The Chi basin borders the Mekong basin to the north, the Mun basin to the south, the Mekong and the Mun basins in the east, and the Pa Sak basin to the west (กรมทรัพยากรน้ำ, 2547).

The Chi river flows over limestone of the Ratchaburi, Phu Phan, Phra Wihan, Khok Kruat formutions and salt rock of the Maha Sarakham formation. The water in the Chi river also comes from subwatersheds such as the Lam Pha Niang, Chern and Nam Phrom that flow over limestone and sandstone and it flows to Pong river (อภิศักดิ์ โสมอินทร์, 2525).

The Chi basin experiences three seasons each year, the rainy season, the winter season and the summer season. The rainy season from May to the middle of October, influenced by the southwest monsoon. The winter season (the middle of October - February) is influenced by the northeast monsoon and in the 2000. The average amount of precipitation per year is 1,174 mm. Accordance with the measured at 7 stations in the Chi river basin (กรมทรัพยากรน้ำ, 2544).

This research studied water quality in the upper part of the Chi river basin and covered 14 subwatersheds in 7 provinces, namely Petchabun, Chaiyaphum, Nakhon Ratchasima, Loei, Udon Thani, Nong Bua Lam Phu and Khon Kaen. The overall area of the upper part of the Chi river basin is about 29,525 square kilometers.

2.2 Physical Factors

2.2.1 Temperature

The temperature of the natural water sources varies depending on the sunlight, season, ambient air temperature, latitude and longitude, topographical condition, depth, turbidity, water volume, general environment of water sources including heat from biochemical reaction of microorganism, and heat from human and animal activities, especially the heat from cooling water of industrial plant discharged into river (EPA, 1973). Water temperature has a large influence the organisms living in the water, and it influences biological activity and chemical processes. For example, water temperature affects the rate of plant photosynthesis, the timing of reproduction and migration, and the metabolic rates of aquatic organisms (Clean Virginia Waterways, www, 2006). In addition, the temperature of water also affects the solubility of oxygen in water. When the temperature of water is increased, the solubility of oxygen is decreased. For example, fresh sterile water at 0°C can contain up to 14.6 mg of oxygen per liter of water, but at 20°C it can hold a maximum of only 9.2 mg of oxygen per liter. Therefore, variations in temperature drastically affect freshwater organisms (The National Estuarine Research Reserve System, www, 2004). The temperature affects the rate of growth and reproduction of fish (วิรัช จิ๋วแหยม, 2544). For example, in catfish (clarias), a temperature range of 29 - 37°C supports healthy growth. With extreme temperature change, many organisms will die. Change in the long - term temperature average may cause change in the species that are present in the ecosystem (Waterwatch Australia National Technical annual, www, 2002).

2.2.2 Turbidity

Turbidity is a measure of the ability for light to transmit through the water column. As suspended solids increase in the water, the amount of light traveling through the water column is reduced (The National Estuarine Research Reserve System,www, 2004). Turbidity in the water is caused by suspended matter such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds and plankton and other microscopic organisms (Greeberg, Clesceri and Eaton, 1992). The increase in human activities, particularly urbanization, agricultural and industrial activities has led to increasing eutrophication i.e. to an increase of nutrients (NO_3^- , NH_4^+ , PO_4^{3-}), the proportions of which depend on the type of wastes, and higher levels of suspended solids make the water increasingly turbid (Lundin and Linden, 1993). If penetration of light into the water is restricted, photosynthesis of green plants in the water is also restricted. This means less food and oxygen is available for aquatic animals. Plants that can either photosynthesis in low light or control their position in the water, such as blue - green algae, have an advantage in highly turbid waters (Waterwatch Australia National Technical Manual, www, 2002). High levels of turbidity over long periods of time can greatly diminish the health and productivity of aquatic ecosystems. Suspended particles can clog gills of fish and other aquatic animals. Many more animals living in water feed by filtering the water, and their filtering - feeding system can become impaired when suspended material is present water in large quantities. Turbid water also reduces photosynthesis in submerged aquatic plants, as light can not penetrate as far into the water. When the suspended particles settle out, they can cover the feeding and spawning grounds of aquatic animals, thereby destroying critical habitat (Clean Virginia Water ways, www, 2006).

2.2.3 Water Velocity

Water velocity will be calculated by averaging the time it takes a float to travel a marked distance and dividing the distance of the course by the average time (Nolan, www, 2001). The rate of water velocity is influenced by topography, rainfall, structures and aquatic vegetation. Typically, the speed of water flow affects the amount of dissolved oxygen. If the water velocity is fast, more oxygen is dissolved. However, the extreme water velocity will destroy benthic macroinvertebrate and fish nesting areas (Boguet River Association, www, 2006). When there is little water in the waterway (low flow) most of water entering the stream will be from under ground seepage, and the flow rate is slow. Sediment settles quickly to the bottom, sections of the stream will become semistagnant resulting in low dissolved oxygen concentration,algal growth will increase if there is adequate light, leading to algal blooms, and salinity and water temperature may increase to values that affect the biota in the waterway (Waterwatch Australia National Technical Manual, www, 2006). High water velocity leads to better dissolving of oxygen. Therefore, the water quality is increased.

2.2.4 Electrical Conductivity

Electrical conductivity is a measure of an aqueous solution's ability to carry an electric current. This ability depends on the presence of ions, concentration, mobility and temperature of measurement (Greenberg, Clesceri and Eaton, 1992). The unit of electrical conductivity is measured in millisiemens per metre (1 mS/m = 10 μS/cm = 10 μmhos/cm). The electrical conductivity of most freshwater ranges from 10 to 1,000 μS/cm but may exceed 1,000 μ S/cm, especially in polluted waters, or those receiving large quantities of land run - off (World Health Organization, www, 1996). If the value of conductivity increases, this indicates an increase in the amount of substances. In contrast, if the value decreases, the ionization of substances decreases in the water (กรรณิการ์ สิริสิงห์, 2525). While an appropriate concentration of salts is vital for aquatic plants and animals, salinity that is beyond the normal range for any species of organism will cause stress or even death. Salinity also affects the ability of nutrients to plant roots (Waterwatch Australia National Technical Manual, www, 2006). The high value of the electrical conductivity indicates the more value of density of water solubility substance consequently, the water density is increased. It affects dissolving of oxygen in water.

2.3 Chemical Factors

2.3.1 pH

Measurement of pH is one the most important and frequently used tests of water quality. Natural water usually has a pH value in the range of 4 to 9 and most are slightly basic because of the presence of bicarbonates and carbonates of the alkali and alkaline earth metals (Greenberg, Clesceri and Eaton, 1992). pH is defined as the negative logarithm of the hydrogen ion concentration in solution, and the pH scale range is 0 to 14. If the pH value of a solution is less than 7, it indicated that the solution is acidic. On the other hand, if the pH value of solution is more than 7, it indicates that the solution is alkaline (The National, Estuarine Research reserve, www, 2004). Human activities also affect the pH of water bodies in other ways. Acid precipitation is the result of nitrogen oxide gases and sulfur dioxide combining with water in the atmosphere to produce nitric and sulfuric acids. Then, acid precipitation falls into water bodies and makes some of them acidic (Boquet River Association, www, 2006). The pH of most natural water is between 6.0 and 8.5, although lower values can occur in dilute waters high in organic content, and higher values in eutrophic water, groundwater brines and salt lakes (World Health Organization, 1996). Generally, most aquatic organism survives best within a limited pH range. Even small changes in pH are harmful to pH sensitive species. Most fish can tolerate pH values of about 5.0 to 9.0, pH values outside that range can create problems for reproduction and survival. Amphibians are particularly susceptible to acid waters (Boquet River Association, www, 2006).

2.3.2 Alkalinity

Alkalinity is the ability to neutralize acids. The unit of alkalinity is parts per million of calcium carbonate (mg/L$CaCO_3$) (AAA water testing, www, 2001). The main sources for natural alkalinity are rocks which contain carbonates, bicarbonates and hydroxide compounds. Borates, silicates and phosphates also may contribute to alkalinity. Limestone is rich in carbonates, so waters flowing though limestone regions or bedrock containing carbonates generally have high alkalinity, hence good buffering and some conglomerates and sandstones may have low alkalinity and there - fore poor buffering capacity (Wilkes University, www, 2005).The suitable value of alkalinity for fish culture is about 20 - 150 mg/L $CaCO_3$ (วิรัช จิ๋วแหยม, 2544). The total alkalinity concentrations should not be less than 20 mg/L $CaCO_3$ in production ponds. The value of pH can swing widely during the day, measuring from 6 to 10, when alkalinity concentrations are below this level. Large daily changes in pH can cause stress, poor growth and even death of the farmed animals (Wurts, 2006). However, high alkalinity often associated with hard water and high dissolved solids, characteristics that may adversely affect the water's use and taste, but there are no negatively health effects from alkalinity (FM River, www, 2003). Furthermore, alkalinity does not only control the pH of a water body, but also the metal content. Bicarbonate and carbonate ions in water can remove toxic metals by precipitating the metals out of solution in water, such as, arsenic and cadmium (Murphy, www, 2002).

2.3.3 Hardness

The hardness of water is caused by its concentration of divalent cations, principally calcium and magnesium, which tend to precipitate soap (Wetzel and Likens, 2000). The value of the hardness is determined by the quantity of calcium carbonate, and the unit of hardness is measured in milligrams per liter as calcium carbonate (mg/L $CaCO_3$). The hardness of water can be divided into carbonate hardness (determined by concentrations of calcium and magnesium hydrogencarbonates), and non - carbonate hardness (determined by calcium and magnesium salts of strong acid) (World Health Organization, www, 1996). Hardness is also important to aquaculture. Calcium and magnesium are essential in the biological processes of fish (bone and scale formation, blood clotting and other metabolic reaction) (Wurts and Durborow, 1992). In natural water resources, total hardness affects the rate of productivity of the water resources. Soft water does not preserve CO_2 which is used in photosynthesis of plants. The rate of productivity of water resources will increase when total hardness does not exceed 130 mg/L $CaCO_3$. Total hardness will cause decrease in productivity in the water resources (สถาบันประมงน้ำจืด, 2521). Generally, aquatic animals can tolerate a broad range of calcium hardness concentrations. A desirable range would lie between 75 to 200 mg/L $CaCO_3$ (Wurts, 2006).

2.3.4 Dissolved Oxygen (DO)

The term "dissolved oxygen" refers to the amount of oxygen that is dissolved in water at a given temperature and a given atmospheric pressure (Oregon Plan for Salmon and Watersheds, 2006). Units for measuring dissolved oxygen are parts per million (ppm) or milligrams per liter (mg/L). Oxygen is essential to all forms of aquatic life, including those organisms responsible for the self - purification in natural waters. Levels of dissolved oxygen in natural waters vary according to temperature, salinity, turbulence, the photosynthetic activity of algae and plant, and atmosphere pressure (World Health Organization, www, 1996). Fluctuation in levels of dissolved oxygen depends on natural water resources and with the number of plants. The amounts of dissolved oxygen increase during the period of time from morning through afternoon because this is the period of photosynthesis. Levels of dissolved oxygen decrease at night (Discovery Science Center, www, 2006).

Moreover, the temperature of stream water influences the amount of dissolved oxygen; oxygen is dissolved in warm water less than the cold water. Therefore, no riparian trees will also cause an increasing in the temperature of water and also in the amount of dissolved oxygen (Clean Virginia waterways, www, 2006). Human activities have great influence on the quantity of dissolved oxygen because they closely effect the water temperature (Boquet River Association, www, 2006). Lower levels of dissolved oxygen can affect the diversity of aquatic organisms. Some species that cannot tolerate low levels of dissolved oxygen such as, mayfly nymphs, stonefly nymphs, caddisfly larvae and beetle larvae will be displaced by low level of pollution (Earth Force, www, 2006). Knight and Gaufin (1963, quoted in Allan, 1995) studied the relationship between water velocity, oxygen level, and number of aquatic insects. Their findings indicated that all stonefly *Hesperda pacifica*, an aquatic insect, died at a current velocity of 1.5 cm/s while it could survive at a velocity of 7.6 cm/s.

2.3.5 Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand (BOD) refers to the amount of oxygen consumed by bacteria as a result of the oxidation of dissolved organic matters in the sample (Baird, 1999). The units of BOD may be measured in mass (g or kg oxygen), a concentration (mg oxygen per liter), or as a supply rate (oxygen mass per time unit) (Audit My PC, www, 2006). This parameter is used to determine the relative oxygen requirement of waste water and polluted water. If BOD levels are high, dissolved oxygen in the water are decreased because bacteria in the water use the dissolved oxygen to decompose organic matter. The amount of the oxygen in water affects the life cycle of aquatic animals. Most aquatic animals can survive in water with more oxygen such as caddisfly larvae, mayfly and stonefly nymphs. Whereas, some species can survive in water with less oxygen such as carp, midge larvae and sewage worms. It is obvious that the value of BOD should be monitored regularly because the value of BOD indicates the quality of water. The finding will be used to protect the diversity of organisms in lakes, rivers, or streams (Boguski, 2006).

2.3.6 Phosphate

Phosphorus is one of the most common elements on earth and is essential to all living organisms. In nature it always occurs combined with other elements, forming phosphates. Phosphate resources are located in the earth's crust in the form of phosphate rock (Natural History Museum, www, 2005). The phosphate found in natural waters mainly exists as the orthophosphate ion (PO_4^{3-}). However, the polyphosphates namely $P_3O_7^{4-}$ and $P_3O_{10}^{5-}$ are frequently encountered. These polyphosphate ions may be hydrolyzed to produce the orthophosphate (Lancashire, www, 2005). Orthophosphate is a readily available to the biological community and typically found in very low concentrations in unpolluted waters. Poly forms are used for treating boiler waters and in detergents. In water, they transform into orthophosphate and biome available for plant uptake (Wilkes University, www, 2006). Phosphate is essential for all living things because phosphate is a component of DNA, RNA, genes, and chromosomes (Potash & Phosphate Institute of Canada, www, 2006). Domestic, agricultural, and some industrial waste are sources of soluble phosphate in water bodies (Horne and Goldman, 1994). Phosphate can stimulate the growth of plankton and aquatic plants which provide food for larger organisms, such as zooplankton, fish, humans, and other mammals (Wilkes University, www, 2006). However, a large amount of phosphate in the water body promotes the rapid growth of algae and aquatic plants. This condition is known as eutrophication or algae bloom.

The rapid growth of aquatic vegetation causes the death and decay of vegetation and aquatic life because of less dissolved oxygen (Ky water watch, www, 2006).

2.3.7 Nitrate

The nitrate ion is a polyatomic anion with the empirical formula NO_3^- and a molecular mass of 62.01 daltons; it consist of one central nitrogen atom surrounded by three identical oxygen atoms in a trigonal planar arrangement (Wikipedia, www, 2006). In generally, nitrate is a form of dissolved nitrogen that occurs in soil and water. It is an important source of nitrogen for plants and animal life (Conrad, Carey, Webb, Dinger, Matthew and McCourt, 1999). All living things need nitrogen to build many essential components for example, proteins, DNA, RNA and vitamins, as well as hormones and enzymes. However, animals can not use simple forms of nitrogen such as nitrate and ammonium. They use other forms of nitrogen for example, amino acid and nucleic acids (Nitrate Elimination, www, 2000). Drinking water with elevated nitrate concentration affects on health especially in infants, e.g. methemoglobinemia or "blue baby syndrome" (Daniels and Mesner, www, 2005). Nitrate is normally the most common form of combined inorganic nitrogen in lakes and streams. The concentration and rate of supply of nitrate is intimately connected with land use practices on a watershed. Major sources of nitrates in streams and lakes are runoff from agriculture and sewage discharges from communities (Horne and Goldman, 1994). When nitrate is added to a body of water, the water becomes enriched and causes the growth of plants and algae. The process of enriching water is allied eutrophication (Cohen, www, 2003). The result of the process makes water turbid, and there is a lot of oxygen in the daytime, but it becomes anoxic at night. Some species produce toxins, notably blue - green algae which increase in numbers when eutrophication occurs (Jeffries and Mills, 1993).

2.3.8 Ammonia

Ammonia is a compound of nitrogen and hydrogen with the formula NH_3 at standard temperature and pressure ammonia is a gas (Wikipedia, www, 2006). When dissolved in water, normal ammonia NH_3 reacts to form an ionized species called ammonium (NH_4^+). The ammonium ion is rapidly take up by phytoplankton and other aquatic plants (Toefz, 1971, quoted in Horne and Goldman, 1994). However, the ammonium ion is not toxic to most plants except at very high concentrations or elevated pH values (Horne and Kaufman, 1974 quoted in Horne and Goldman1994). Ammonia is found throughout the environment in the air, soil, water, plants and animals including humans (Agency for Toxic Substances and Disease Registry, www, 2004). The major source of ammonia is from inflowing rivers, precipitation, atmosphere dust, or in directly from N_2 fixation. Most of the ammonia in rain is probably derived from aerosols originating in the oceans, animal or bacterial excretions rather than in volatilization of ammonia gas from the lake surface (Horne and Goldman, 1994). Generally, unpolluted waters contain low concentration of ammonia compounds, usually less than 0.1 mg/L as nitrogen. Total ammonia concentration measured in surface waters are typically less than 0.2 mg/L but may reach 2 - 3 mg/L. Higher concentrations indicate that the water is polluted from domestic sewage, industrial waste and fertilizer runoff (Chapman, 1996). The toxicity of liquid solutions is primarily due to the presence of NH_3, the percentage of which increase with pH and temperature. Therefore, the toxicity of "total ammonia" is greater in more alkaline water at higher temperatures. It is also more toxic under conditions of decreased amounts of oxygen (Department of environment and heritage, www, 2005).

2.4 The Study of Using Benthic Macroinvertebrates as an Indicator of Water Quality

Natural events and anthropogenic influences can affect the aquatic ecosystem in many ways; synthetic substances may be added to the water, the hydrological regime may be altered or the physical or chemical nature of the water may be changed. Different organisms respond differently to changes in water quality. The most extreme responses include death or migration to another habitat (Chapman, 1996). Therefore, monitoring of water quality is necessary. There are many methods used to monitor water in rivers. The physical, chemical and biological properties can be measured such as temperature, turbidity and water velocity for physical parameters, dissolved oxygen, biochemical oxygen demand, pH for chemical parameters, and benthic macroinvertebrates for biological parameters (Wannathong, 2001). Biological monitoring is one tool that can be used. The use of biomonitoring is growing because it can detect cumulative physical, chemical and biological impacts of stream - degrading activities (Karr and Chu, 1999).

Benthic macroinvertebrates have been used for water quality monitoring since the mid - 1800's and surveillance of aquatic habitat quality using benthic macroinvertebrate communities as indicators of biotic integrity has become common practice (Cairns and Pratt, 1992). Moreover, macroinvertbrates are especially useful for this purpose because they are (a) common in most streams, (b) readily collected, and (c) have life cycles ranging from a few weeks to a few years (Adams, 2002).

Benthic macroinvertebrates are used to monitoring changes in genetic composition, bioaccumulation of toxicants, toxicological testing in the laboratory and field, measurements of changes in population numbers, community composition, or functioning (Rosenberg and Resh, 1993).

The use of benthic macroinvertebrates to assess water quality began in Germany in the early part of the 20th century. Cairns and Pratt (1993, quoted in Merritt and Cummins1996) reported that the scientist developed the idea of saprobity (the degree of pollution) in rivers as a measure of the extent of contamination by sewage, which results in decreases of dissolved oxygen, and its effect on life in rivers.

The Hilsenhoff Biotic Index (HBI) is popularly used to assess water quality in lotic ecosystems. Originally developed in 1977 by Dr. William Hillsenhoff of the University of Wisconsin - Madison, to assess low dissolved oxygen caused by organic loading in streams. The Wisconsin Department of Natural Resources began using the HBI in 1979 to assess water quality in a streams and rivers as part of several non - point - source pollution monitoring programs within the agency (History of the Hilsenhoff Biotic Index, www. 2004). The Hilsenhoff Biotic Index represents the average weighted pollution tolerance value of all arthropods present in a sample. Tolerance values range from 0 for organisms very intolerant of organic wastes to 10 for organisms very tolerant of organic wastes (Soil & Water Conservation Society of Metro Halifax, www, 2006). In 1987, the Hilsenhoff Biotic Index was developed for evaluating organic pollution in Wisconsin streams using insect species. Hilsenhoff (1988) adapted the BI to create a family biotic index (FBI) by using the tolerance values of insect families, a taxonomic level more appropriate for rapid bioassessment. The FBI was developed to assess the impacts from organic pollution based on the relative abundance of macroinvertebrate families with varying tolerance to organic pollution, but has been shown to be sensitive to other forms of water quality degradation (Resh and Jackson, 1993 quoted in Rosenberg and Resh, 1993).

Diversity index represents a measure of the distribution of individuals among different taxa present in a sample. Resh and McElravy (1993) found that Shannon - Wiener Index is the most commonly applied index in a survey of 90 lentic and lotic benthos field studies. The Shannon - Wiener Index value range between 1.5 to 3.5 with higher values representing higher diversity (Lillie et al., 2003). The Shannon - Wiener Index calculated from determination to species level was always significantly higher than values from genus or family level determinations. However, the use of species genus or family level determination will depend on the objectives of the studies. If the purpose of a study is simply enough to detect an impact of a perturbation on benthic macroinvertebrate communities, determination to family level may be used. On the other hand, there is an increasing need for rapid and low cost methods to assess water quality. In this way, determinations to low taxonomic level are difficult and are performed only by specialists who are becoming less and less numerous (Chiangthong, 2005).

The EPT index is the total number of distinct taxa within the orders Ephemeroptera, Plecoptera, and Trichoptera (Saver, 2001). The EPT index generally increases with increasing water quality. The index value summarizes the taxa richness within the insect groups that are generally considered pollution sensitive. This was developed for species level identifications; however, the concept is valid for use at family level identifications. Headwater streams that are naturally unproductive may experience an increase in taxa, including EPT taxa, in response to mild organic enrichment (Plafkin et al., 1989). The EPT index is calculate by counting EPT taxa, including large rare taxa, from the subsampling effort (Saver, 2001).

The Biological Monitoring Working Party (BMWP) was recognized in the late 1960's and early 1970's that biological information provided a more integrated measure of river quality than chemical monitoring, especially in terms of the polluting effects of mixtures of chemicals and the continuous monitoring that in situ flora and fauna provide (Logan, 2001). The BMWP score is calculate by adding the individual scores of all indicator organisms present. The organisms are identified to the family level and then each family is allocated a score between 1 to 10. The score value for individual families reflect their pollution tolerance; pollution intolerant families have high scores and pollution tolerant families have low scores (Friendrich et al., 1996). The average sensitivity of the families of the organisms present is known as the Average Score Per Taxon (ASPT) and can be determined by dividing the BMWP score by the number of taxa present (Chapman, 1996). The ASPT score tends to reduce the impact of occasional finds of high scoring taxa (Leeds et al., www, 1996). Now there are several applied BMWP scores and ASPT from the original of Britain, such as the BMWP and ASPT of Spain, the BMW and ASPT of Indian, Nepalese Biotic score/ Average Score Per Taxon and in Thailand, the score was applied by Mustow in 2002 (Chiangthong, 2005).

2.5 The Research Studied

Apfelbeck (www, 1999) studied the development of biocriteria for wetland in Montana. The results of the study were revealed that diatoms and mrcroinvertebrates were most useful for evaluating the biological integrity of perennial wetlands with open water environments that had relatively stable water levels and were not excessively alkaline or saline. This research concluded that multivariate analysis was a useful tool for developing a wetland classifying wetlands for the development of biocriteria. Similarity, Cora, Goulart, Moreno and Callisto (2002) examined the rapid assessment of river water quality using an adapted BMWP index a practical tool to evaluate ecosystem health. The results of the study were found that the use of the adapted BMWP index in the upper and middle Doce River basin showed that biotic indices can be an important and valuable tool in determining ecosystem health in long - term biomonitoring programs. This approach provides a means for the local environmental agencies for the conservation of the natively freshwater resources and the management and restoration of impacted areas. Davis, Golladay, Vellidis and Pringle (2003) studied the macroinvertebrate biomonitoring in intermittent coastal plain streams impacted by animal agriculture. Davis et al. (2003) found that four metrics (percent Crustacea, Isopoda, Diptera and EPT) had no overlap between values for the most impacted and the least impacted site during the flow period, but no metrics were able to detect more discrete differences among sites. Sites were physically and biologically similar during the intermittent period when natural stresses were high, with many metrics, such as percentages of dominant family, burrowers, chiromomids and dipterans becoming similar at all sites. In 2000, Pires, Cowx and Coelho studied the benthic macroinvertebrate communities of intermittent streams in the middle reaches of the Guadiana Basin (Portugal). The research concluded that nerally, Plecoptera and ephemeroptera were found in the upstream sampling sites. Wider and deeper sites were associated with the presence of Diptera and were least diverse. High values for both the Shannon - Wiener diversity index and average score per taxon were usually found at upstream sites where Ephemeroptera and plecoptera predominanted. The data suggest that macroinvertebrates have great caught periods, both in term of taxonomic diversity and number of individuals. In Malaysia, Long, Abang and Rahim (2002) investigated the macroinverterbrate community of the fast flowing river in the Crocker Range Nation Park Sarbah. This paper reported that all the six rivers surveyed demonstrated excellent water quality. The assemblages of taxa reported as that typical of the macroinvertebrate fauna in tropical rivers. The overall macrainvertebrate density ranges from 71 to 303 individuals per 1 square meter. In Nepal, Sharma et al. (2005) studied assessing water quality for ecosystem health of the Babai river in Royal Bardia National Park. The metrics were used for assessing the water quality such as Nepalese Biotic score, Shannon - wiener generic diversity, Diversity index, Community loss, Taxa richness, EPT Index, Chironomidae taxa.The results were found that all four sites showed signs of pollution. Even the reference site, which was to act as a control, had a high loading of organic content, perhaps due to soil and debris from the previous years monsoon and the presence of poison resulting in large scale death of aquatic life. In New Zealand, Death (2000) examined the effect of land use on species area relationships in benthic stream invertebrates. The results of this study were revealed that land use changes between the upper and lower sites on the Kahuterawa stream had a clear impact on the community composition of benthic invertebrates. The more pristine upper site was dominated by Mayfly and Tricopteran taxa characteristic of cleaner water, whereas the lower site had a greater abundance of Chironomidae and Mollusca. Furthermore, in America, Yandora (www, 1998) studied the rapid bioassessment of benthic macroinvertebrates illustrates water quality in small order urban streams in a North Carolina Piedmont City. The metrics were used for assessing the water quality such as total taxa richness, North Carolina biotic index value, EPT abundance, EPT richness, ratio of EPT and Chironomidae, percent Tubificidae, and percent dominant species. Sites upstream of urban activity showed high diversity and overall good water quality. Poor to fair water quality rating were seen downstream of urban activity. However, the condition of biotic communities was directly related to habitat and water chemistry. Habitat is degraded in urban areas due to dredging, chanelization and impaired riparian buffer zones that contribute to poor species diversity. Simirality, Stepenuck (www, 2002) investigated impacts of urban land use on macroinvertebrate communities in south eastern Wisconsin streams. This report concluded that most urban land uses were negatively correlated with the Shannon diversity index, percent of pollution intolerant Ephemeroptera, Plecoptera, and Trichoptera individuals, and generic richness. Non - urban land uses were positively correlated with these same metrics. The Hilsenhoff biotic index indicated that stream quality declined with increased urbanization.

In Thailand, Chantaramongkol et al. (1999) studied biodiversity of Trichoptera in Thailand and their application for water quality assessment. Samples were collect from 57 different sites in national parks, wildlife sanctuaries, waterfalls, reservoirs, main rivers, and streams, and also for Thailand. There were 572 species of Trichoptera. Eighteen species of Trichoptera could be used as bioindicators for water pollution. The results of this study indicate that some Trichoptera species can be successfully used as bioindicators to assess anthropogenic pollution in tropical Asian lowland rivers. In addition, Sangpradup, Inmuong, Hanjavanit, Asachai and Udonphimai (2001) studied distribution of Ephemeropteran, Plecopteran and Trichoptera larvae in watershed streams of Northeast Thailand. Samples were collected in 22 headwater streams of the Chi, Pa sak and Mekong basins.

Ephemeropteran, Plecopteran, and Trichoptera larvae were very diverse with at least 46, 13 and 64 species, respectively, being identified. Forest cover, altitude, water depth, water velocity, dissolved oxygen, conductivity and total dissolved solids affected the distribution of larvae. Maketon, Kittiwarachet, Somsiri and Ngamprayad (1997) studied the benthic fauna and water quality in the Chao Phraya river. The results of the study found that the greatest number of families was twenty four at the estuary, and the least number was found at Amphoe Muang Singhaburi, Singhaburi Province. The highest indices of species diversity and evenness index were 2.08 and 0.79 respectively, and the lowest values were 0.12 and 0.05 respectively. The indices indicated that the water quality in upstream and the middle were very good to fair instead of fair to poor, but the downstream qualities were poor at all sites. In addition, สารสิน, ยรรยง และ วงศ์วิวรรธ (www, 2539) studied the performance of physicochemical and biological variables in environment impact analysis: an investigation of the most frequently polluted sites of the Pong River, Khon Kaen Province. The biological variables, using diversity indices (Shannon - Wiener Indices - H′), Biological Monitoring Working Party Score (BMWP) and Average Score Per Taxon (ASPT), perform effectively superior to the physicochemicals in evaluating river water quality status. The results found that the biological variables when using them comparatively for detecting water pollution, the H′ level appears to be efficient as negative inferential, the ASPT is considerably positive and the BMWP exits also indicated a strong relationship between biological indices and dissolved oxygen levels.

CHAPTER III

RESEARCH METHODOLOGY

This study covers important factors associated physicochemical, the quantity and biodiversity of benthic macroinvertebrates in the upper parts of Chi river basin.

3.1 The Sampling Sites Description

The study area is located in the upper parts of Chi river basin (Figure3.1) that could assign to 10 sampling sites with different land used. So, there were different impacts to water quality and benthic macroinvertebrates. The 10 sampling sites are shown in Table 3.1

Table 3.1 The 10 sampling sites in upper part of the Chi river basin

Sampling sites	District	Province
1. Ban Tad Ton	Muang	Chaiyaphum
2. Ban Huai Hai	Ban Khwao	Chaiyaphum
3. Ban Non Pluai	Nong Bua Rawe	Chaiyaphum
4. Ban Non Pho	Ban Khwao	Chaiyaphum
5. Ban Khai	Muang	Chaiyaphum
6. Ban Kaeng Kham	Kaeng Sanam Nang	Nakhon Ratchasima
7. Ban Yang Wai	Khon Sawan	Chaiyaphum
8. Ban Tanang Luan	Chonnabot	Khon Kaen
9. Ban Non Som Boon	Ban Haet	Khon Kaen
10. Ban Tha Phra	Muang	Khon Kaen

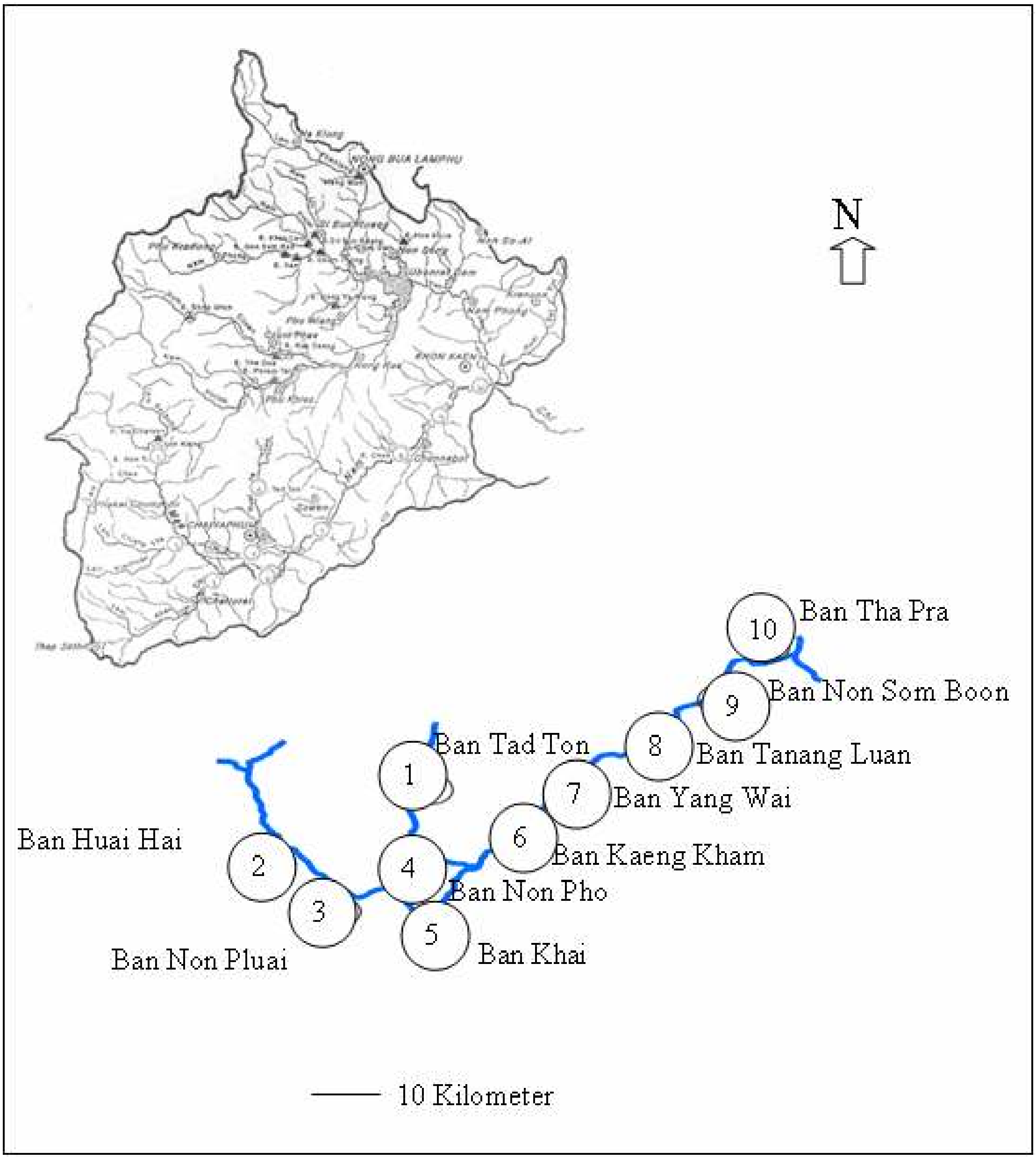

Figure 3.1 The upper part of Chi river basin and 10 sampling sites

3.1.1 Site 1

Site 1 is located in Huai Pa Tao stream at Ban Tad Ton, Muang District, Chaiyaphum Province at about 15° 57′ 02″ N 102° 02′ 00″ E. It is a tributary of Chi river. Most areas of sampling site are covered by bamboo plants forest. The substrates of sampling site are silt and clay. The water velocity was slow (Figure 3.2).

Figure 3.2 Ban Tad Ton sampling site

3.1.2 Site 2

Site 2 is located adjacent Ban Huai Hai, Ban Khwao District, Chaiyaphum Province at about 15° 51′ 36″ N 101° 43′ 03″ E. The sampling site area is covered by high grass in rainy season but died out in the other seasons. The river banks are covered with sand. The water velocity was slow (Figure 3.3)

Figure 3.3 Ban Huai Hai sampling site

3.1.3 Site 3

Site 3 is located adjacent Ban Non Pluai, Nong Bua Rawe District, Chaiyaphum Province at about 15° 46′ 06″ N 101° 00′ 48″ E. The river banks are covered with small grass and shrub. In summer, the water velocity was slow and had small amount of water, but there was very high water velocity and had large amount of water in rainy season (Figure 3.4).

Figure 3.4 Ban Non Pluai sampling site

3.1.4 Site 4

Site 4 is located in Ban Non Pho, Ban Khwao District, Chaiyaphum Province at about 15° 41′ 52″ N 102° 00′ 55″ E. The sampling site is covered with small plants and some parts had soil erosion. The sampling sites are sand and covered with litter. The water velocity was very slow in summer but had very high speed water current in rainy season (Figure 3.5).

Figure 3.5 Ban Non Pho sampling site

3.1.5 Site 5

Site 5 is located adjacent Ban Khai, Muang District, Chaiyaphum Province at about 15° 41′ 15″ N 102° 00′ 55″ E. The river banks are covered with grass and shrub. The substrates are silt and clay. The water velocity was very slow in summer and had very high water velocity in rainy season (Figure 3.6).

Figure 3.6 Ban Khai sampling site

3.1.6 Site 6

Site 6 is located adjacent Ban Kaeng Kham, Kaeng Sanam Nang District, Nakhon Ratchasima Province. It is located between 15° 51′ 13″ N 102° 19′ 09″ E. The left bank is covered with herbs, shrubs, and trees, whereas, it is high slope of river bank and soil erosion in some parts. The riverbed is composed of sand and cobbles. The water velocity was very slow in summer, conversely it was very high water velocity in rainy season (Figure 3.7).

Figure 3.7 Ban Kaeng Kham sampling site

3.1.7 Site 7

Site 7 is located in Ban Yang Wai, Khon Sawan District, Chaiyaphum Province at approximately15° 51′ 13″ N 102° 19′ 09″ E. The right bank is covered with herbs, shrubs and trees, the left bank is covered with bamboo forest. At the sampling point the river banks are covered with muddy-sand. The river had no movement in summer whereas it had high speed in rainy season (Figure 3.8).

Figure 3.8 Ban Yang Wai sampling site

3.1.8 Site 8

Site 8 is located in Ban Tanang Luan, Chonnabot District, Khon Kaen. It is located between 16° 05′ 37″ N 102° 34′ 39″ E. The river banks are covered with grasses. The riverbed is composed of muddy-sand. The water velocity was very slow in summer. On the other hand, it was very fast in rainy season (Figure 3.9).

Figuer 3.9 Ban Tanang Luan sampling site

3.1.9 Site 9

Site 9 is located adjacent Ban Non Som Boon, Ban Haet District, Khon Kaen Province at about latitude16° 16´ 26″ N 102° 46´ 44″ E. The riverbanks are covered with shrubs and grasses. The riverbed is composed of muddy - sand. The water velocity was very slow in summer and it had high speed current in rainy season (Figure 3.10).

Figure 3.10 Ban Non Som Boon sampling site

3.1.10 Site 10

Site 10 is located adjacent Ban Tha Phra, Muang District, Khon Kaen Province at about latitude 16° 21´ 04″ N 102° 48´ 11″ E. The left riverbank is covered with shrubs and climber, whereas there is grasses on right bank. The riverbed is composed of muddy-sand. The water velocity was very slow in summer and it had high water velocity in rainy season (Figure 3.11).

Figuer 3.11 Ban Tha Phra sampling site

3.2 Physicochemical of Water Quality

3.2.1. The Physical Factors of Water

The study examined temperature, turbidity, electrical conductivity and water velocity

3.2.2. The Chemical Factors of Water Quality

The study examined pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), hardness, nitrate, ammonia, phosphate, and alkalinity.

3.3 The Benthic Macroinvertebrates

This study determined the water quality of the upper parts of Chi river basin using benthic macroinvertebrates.

3.4 The Equipment Used in This Study

3.4.1 Field Equipment and Chemicals

3.4.1.1 Rectangular dip net

3.4.1.2 White sheet or plastic

3.4.1.3 Buckets

3.4.1.4 White enamel or shallow plastic pans

3.4.1.5 Small jars or vials

3.4.1.6 Seventy percent alcohol solution

3.4.1.7 Forceps, tweezers, spoon and small paint brushes

3.4.1.8 Hand-held magnifiers

3.4.1.9 Data sheet, pencil and clipboard

3.4.1.10 Water sampler

3.4.1.11 BOD bottles and water sampler bottles

3.4.1.12 Multi-parameter analyzer Consort C533 version 2.2

3.4.1.13 Camera

3.4.1.14 Nitric acid

3.4.1.15 Sulfuric acid

3.4.1.16 Dropper

3.4.1.17 Label papers and pencils

3.4.1.18 Equipment to measured water velocity

3.4.2 Laboratory Equipments and Chemicals

3.4.2.1 Equipment to analyze biochemical oxygen demand

3.4.2.2 Equipment to analyze phosphate

3.4.2.3 Equipment to analyze nitrate

3.4.2.4 Equipment to analyze ammonia

3.4.2.5 Equipment to analyze hardness

3.4.2.6 Equipment to analyze alkalinity

3.4.2.7 Equipment to analyze turbidity

3.4.2.8 Stereomicroscope

3.4.2.9 Glass sorting dishes

3.4.2.10 Chemical reagents to analyze biochemical oxygen demand

3.4.2.11 Chemical reagents to analyze phosphate

3.4.2.12 Chemical reagents to analyze nitrate

3.4.2.13 Chemical reagents to analyze ammonia

3.4.2.14 Chemical reagents to analyze hardness

3.4.2.15 Chemical reagents to analyze alkalinity

3.4.2.16 Chemical reagents to analyze turbidity

3.4.3 The Study of Physicochemical of Water Quality

3.4.3.1 Temperature

Water temperature was measured in the sampling site with a multi-parameter analyzer Consort C533 version 2.2

3.4.3.2 Electrical Conductivity

Electrical conductivity was measured at the sampling site with a multi - rameter analyzer.

3.4.3.3 Turbidity

Turbidity was measured by turbidimeter, Hach company model 2100 A in the laboratory.

3.4.3.4 Water Velocity

Water velocity was calculated by averaging the time its takes a float to travel a marked distanced and dividing the distance of the course by the average time (Noland, www, 2001).

3.4.3.5 pH

The pH was measured by multi-parameter analyzer Consort C533 version 2.2

3.4.3.6 Alkalinity

Alkalinity was measured by phenolphthalein and methyl orange indicator (APHA, 1998).

3.4.3.7 Hardness

Water hardness was examined by EDTA titration method in the laboratory (APHA, 1998).

3.4.3.8 Nitrate-nitrogen (NO3 - N)

Nitrate-nitrogen was examined by the cadmium reduction method in the laboratory (APHA, 1998).

3.4.3.9 Ammonia- nitrogen.

Ammonia - nitrogen was measured by the Nesslerization technique (APHA, 1998).

3.4.3.10 Phosphate

Phosphate was examined by Ascorbic acid method in the laboratory (APHA, 1998).

3.4.3.11 Dissolved Oxygen

Dissolved oxygen was measured by multi-parameter analyzer Consort C533 version 2.2

3.4.3.12 Biochemical Oxygen Demand

Biochemical oxygen demand was measured by the azide modification method in the laboratory (APHA, 1998)

3.5 Benthic Macroinvertebrate Sampling

The rectangular dip net mesh size 595 μm was used to collect benthic macroinvertebrates which was modified from Barbour et al. (1999).

3.5.1 Sampling Design (modified from Barbour et al., 1999; Environment Protection Authority State Government of Victoria, 1998; Merritt and Cummins, 1996).

A 100 m reach representative of the characteristics of the stream was selected. Whenever possible, the area was at least 100 meters upstream from any road or bridge crossing to minimize its effect on stream velocity, depth, and overall habitat quality. There was no major tributary discharging to the stream in the study area. By using a topographic map, then delineate the sampling reach on a topographic stretch map of the river (100 m length of reach).

Length of sampling zone was 100 m, with in this zone randomly place 3 sampling plots (each side of the river bank) each plot was 10 m long. The width of sampling zone was 1 m from the water's edge (Figure 3.12).

Choose 3 numbers from the random number table among 1 to 10 plots (from each sampling zone side was divided into 10 plots, the length of each plot is 1 × 10 m, but take only 3). Use these numbers to select sampling plots within the reach. With drawing a number to determine whether each sampling plot was located in the sampling zone and managed the same means on another side of the bank (banks are defined as right or left when facing down stream).

3.5.2 Sampling Procedures

A rectangular dip net of 40 × 60 cm and 595 μm of mesh size was used to collect benthic macroinvertebrates.

Sampling begins at the down stream end of the reach and proceed upstream.

Placing the rectangular dip net on the stream bottom and the substrate just upstream from the net was vigorously disturbed by kicking. For layer boulder, the net was held near the area being disturbed so the current carried dislodged animals into it.

3.5.3 Benthic Macroinvertebrates Collection

The collection procedures were modified from the methods of Earth Force (www, 1998), Southern California Bight (1998) and Regional Marine Monitoring Survey (www, 1998) as follows:

Lifted the rectangular dip net out of the water.

After carrying the net to the stream bank, washed the contents into a large bucket filled with stream water. Washing from behind the screen could help to dislodged the animals.

Placed the contents of the net in a white sorting tray, rinsing off adhering material with stream water and dispersing the sample in the water. Pick or wash off any animals clinging to the net and add them to the tray.

Picked out animals with forceps and pipette in to a jar of 70% ethanol. Avoid adding excessive water to the jar from the pipette as this may interfere good preservation.

While picking, shook the tray from time to time to evenly mixed the contents and tilted the tray occasionally to look for animals adhering to it.

Labeled the sample jar with site name, location code, date and replicate number.

Recorded collector's name and picker's name on the field sheet.

Took close-up photographs of the sampling sites.

Identified benthic macroinvertebrates identification keys.

Calculated and evaluated water quality.

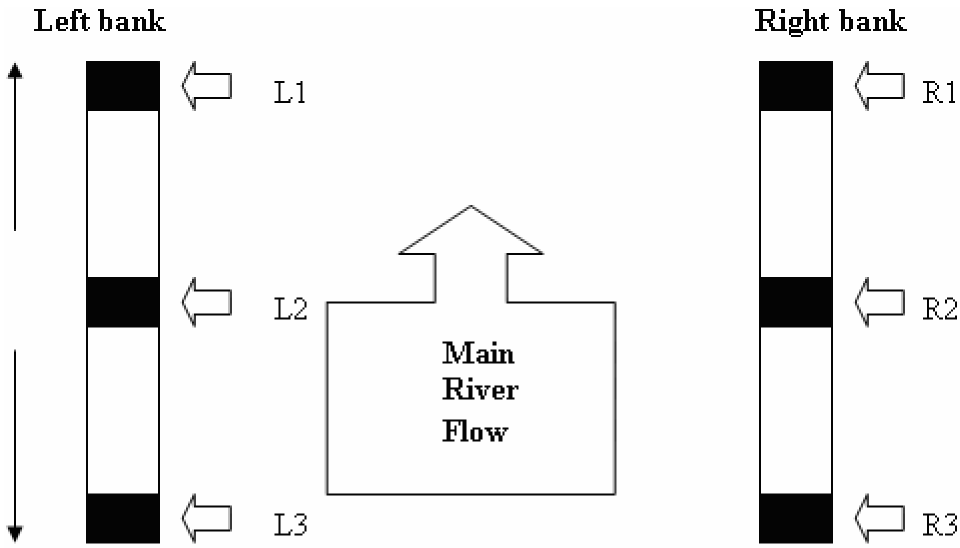

Figure 3.12 Sampling zone and sampling plots (L and R)

3.6 Identification of Benthic Macroinvertebrates

The benthic macroinvertebrates were collected and sorted, they were identified to family in the field and in laboratory using the identification keys by Beauchene (2001), Beauchene and Hoffman (2000), Cartwright (1998), Dean (1999), Dean and Suter (1996), Dudgeon (1999), Lehmkuhl (1979), McCaferty (1998) and Merritt and Cummins (1996).

3.7 Biological Metrics

The indices used to evaluate water quality are as follow : (modified from Citizens'Environment Water, www, 2002).

3.7.1 Hilsenhoff Biotic Index

The Hilsenhoff Biotic Index (HBI) was designed to reflect nutrient status of streams by using the tolerance of organisms to pollution. Tolerance values range from 0 for organisms very intolerant of pollution to 10 for organisms very tolerant of pollution (Appendix C). The Hilsenhoff Biotic Index was calculated from :

$$HBI = \Sigma \frac{n_i a_i}{N}$$

Where

n_i = number of individuals within taxon

a_i = tolerance value a taxon

N = total number of organisms in the sample

3.7.2 Diversity Index

Species diversity index was calculated from the Shannon - Wiener index (H′) (FAO, www, 2006).

$$H' = \sum_{i=1}^{s} p_i \ln p_i .$$

Where

H′ = Diversity Index

p_i = Proportion of individuals of the total sample belonging to ith families

The value of the Shannon - wiener index usually falls between 1.5 to 3.5 and only rarely exceeds 4.5 Diversity values irrespective of the index chosen vary directly with water quality and low diversity may indicate and be unstable community.

3.7.3 BMWP score and ASPT

The Biological Monitoring Working Party (1978) made the first attempt at developing a nationally applicable monitoring system for rivers using benthic macroinvertebrate. The BMWP system assigns point to particulars taxa according to their known sensitivity or tolerance to organic pollution. The most pollution sensitive, such as stone flies, was scored ten, while the most pollution insensitive oligochaete worms were scored one (Appendix D). The average values for each taxon (ASPT - the BMWP score divide by the number of taxa used in its calculation) as it was less prone to sampling errors (Logan, 2001).

$$\text{BMWP} = \sum n_i a_i$$

Where

n_i = number of individuals within taxon

a_i = tolerance value a taxon

$$\text{ASPT} = \frac{\text{BMWP}}{N}$$

Where

N = the number of taxa used in its calculation

3.8 Research Duration

The samples were collected bimonthly from February 2004 to December 2004.

3.9 Statistical Analysis

The data of physicochemical and biological parameters were analyzed by using Statistical Program for Social Science (SPSS) version 11.5 and subject were used to perform the following statistical analysis.

3.9.1 The mean and standard deviation were used to analyze the water quality.

3.9.2 The F - test was used to analyze the relation of water quality

3.9.3 Cluster Analysis was used to grouping the sampling sites by using physicochemical and benthic macroinvertebrates.

3.9.4 Principal Component Analysis was used to analyze the relative proportion of benthic macroinvertebrate orders to water quality and physicochemical factors to biological indices.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter presents the result of the monitoring and assessment of water quality in the upper part of Chi river basin using physicochemical variables and benthic macroinvertebrates as following the topics.

4.1 Physicochemical Factors

The physicochemical factor, p values and the correlation of physicochemical factors, benthic macroinvertebrates orders and biological indices are shown in Table 4.1, Table 4.2 and Table 4.3

4.1.1 Temperature

The water temperature ranged from 23.12 - 35.33°C. The maximum water temperature was 35.33°C at site 7 (Ban Yang Wai) in the summer season (April 2004), but the minimum was 23.12°C at site 1 (Ban Tad Ton) in the late winter season (February 2004). There was no significant different between sites but there was significant different between seasons ($p<0.05$). However the water temperature did not significantly differ between February versus December and June versus August. The results revealed that the water temperature was lower in the winter seasons when compared to the other season as it was affected by the climate and influenced by Northeast monsoons.

Table 4.1 Physicochemical factors in the upper part of Chi river basin from February to December 2004

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	mean	P
Temperature	27.3 ±0.9	28.6 ±1.3	28.7 ±1.1	28.7 ±1.2	27.6 ±1.6	28.7 ±1.7	29.1 ±1.9	30.4 ±1.7	28.8 ±1.6	28.1 ±1.5	28.6 ±0.45	0.97
Turbidity	3.1 ±1.3	28.7 ±24.3	39.6 ±27.2	16.3 ±8.4	17.6 ±7.2	14.9 ±9.2	20.1 ±10.9	30.3 ±15.9	32.9 ±22.4	36.1 ±28.2	24 ±5.4	0.93
EC	54.7 ±25.4	259.8 ±29.9	254.6 ±34.4	426.8 ±129.6	605.2 ±148.8	718.3 ±155.4	755.9 ±158.1	596.3 ±129.5	687.5 ±129.4	500.6 ±78.1	486.0 ±43.9	0.00
Velocity	0.5 ±0.3	0.6 ±0.4	0.14 ±0.0	0.15 ±0.0	0.48 ±0.3	0.07 ±0.0	0.07 ±0.0	0.4 ±0.3	0.1 ±0.1	0.06 ±0.0	0.27 ±0.17	0.63
PH	6.7 ±0.2	7.3 ±0.1	7.4 ±0.2	7.4 ±0.1	7.3 ±0.1	7.2 ±0.1	7.4 ±0.1	7.2 ±0.1	7.4 ±0.2	7.5 ±0.3	7.3 ±0.1	0.07
Hardness	78.8 ±17.1	157.9 ±14.1	140.4 ±15.8	149.2 ±14.9	150.7 ±22.2	157.9 ±21.6	135.7 ±21.6	113.2 ±14.7	116.7 ±16.0	99.0 ±15.6	129.9 ±6.1	0.03
Alkalinity	25.2 ±2.3	29.2 ±3.0	27.0 ±2.9	28.2 ±2.8	25.6 ±3.2	25.4 ±3.5	25.5 ±2.8	23.1 ±2.8	22.9 ±2.5	23.1 ±2.4	25.5 ±0.8	0.82
DO	6.1 ±0.4	6.2 ±0.6	5.6 ±0.5	5.6 ±0.2	5.6 ±0.3	5.1 ±0.3	5.7 ±0.7	5.1 ±0.3	5.9 ±1.2	5.6 ±0.5	5.7 ±0.2	0.96
BOD	1.4 ±0.1	1.8 ±0.4	1.8 ±0.3	1.7 ±0.4	1.5 ±0.2	2.0 ±0.3	2.7 ±0.4	2.2 ±0.4	7.3 ±4.9	3.3 ±0.7	2.6 ±0.5	0.34
phosphate	0.01 ±0.0	0.02 ±0.2	0.02 ±0.0	0.01 ±0.2	0.02 ±0.0	0.02 ±0.0	0.2 ±0.1	0.02 ±0.3	0.03 ±0.0	0.02 ±0.1	0.02 ±0.1	0.99
nitrate	0.2 ±0.1	0.1 ±0.0	0.2 ±0.2	0.2 ±0.0	0.1 ±0.1	0.1 ±0.2	0.2 ±0.3	0.2 ±0.0	0.2 ±0.2	0.2 ±0.0	0.2 ±0.1	0.82
Ammonia	0.5 ±0.5	0.1 ±0.0	0.2 ±0.1	0.2 ±0.0	0.2 ±0.1	0.1 ±0.0	0.2 ±0.0	0.2 ±0.1	0.2 ±0.1	0.1 ±0.1	0.2 ±0.0	0.59

Table 4.2 The correlation of physicochemical and benthic macroinvertebrates orders in upper part of Chi river basin

	TEMP	DO	PH	TUR	EC	HAR	ALK	BOD	PO	NO	NH	VE	odon	him	dec	tri	iso	gas	eph	ven
TEMP	1.00	-0.17	0.16	0.16	-0.15	-0.25	-0.18	0.16	0.17	0.24	-0.04	0.07	-0.19	0.01	-0.11	0.01	-0.29	-0.04	-0.20	0.18
DO	-0.17	1.00	0.25	-0.20	0.09	0.12	0.18	-0.15	-0.16	-0.03	0.01	-0.03	0.19	-0.09	-0.10	0.09	0.13	-0.14	0.00	-0.11
PH	0.16	0.25	1.00	0.00	0.26	0.25	0.09	0.06	0.01	-0.21	-0.27	-0.09	-0.08	0.01	-0.11	-0.15	-0.07	0.12	-0.09	0.11
TUR	0.16	-0.20	0.00	1.00	-0.37	-0.49	-0.46	-0.04	0.87	0.26	-0.01	0.40	-0.32	0.10	-0.10	-0.09	-0.14	-0.03	-.08	0.00
EC	-0.15	0.09	0.26	-0.37	1.00	0.60	0.34	0.23	-0.40	-0.37	-0.19	-0.36	0.04	0.04	-0.05	-0.20	0.23	0.11	0.12	0.04
HAR	-0.25	0.12	0.25	-0.49	0.60	1.00	0.68	0.07	-0.53	-0.44	-0.23	-0.33	0.36	-0.10	-0.01	-0.18	0.20	-0.02	0.09	-0.04
ALK	-0.18	0.18	0.09	-0.46	0.34	0.68	1.00	0.12	-0.48	-0.35	-0.14	-0.30	0.43	-0.18	-0.07	-0.12	0.13	-0.12	0.06	-0.02
BOD	0.16	-0.15	0.06	-0.04	0.23	0.07	0.12	1.00	-0.09	-0.02	-0.09	-0.04	0.03	0.41	-0.04	-0.06	-0.05	-0.01	-0.03	-0.01
PO	0.17	-0.16	0.01	0.87	-0.40	-0.53	-0.48	-0.09	1.00	0.28	0.21	0.50	-0.33	0.11	-0.11	0.14	-0.11	-0.01	-0.13	0.00
NO	0.24	-0.03	-0.21	0.26	-0.37	-0.44	-0.35	-0.02	0.28	1.00	0.14	0.20	-0.41	0.00	-0.06	0.20	0.03	0.01	-0.03	0.06
NH	-0.04	0.01	-0.27	-0.01	-0.19	-0.23	-0.14	-0.09	0.21	0.14	1.00	0.41	0.02	-0.14	0.04	0.78	-0.04	-0.04	0.01	-0.02
VE	0.07	-0.03	-0.09	0.40	-0.36	-0.33	-0.30	-0.04	0.50	0.20	0.41	1.00	-0.17	0.04	-0.03	0.35	-0.12	-0.07	-0.07	-0.05
odon	-0.19	0.19	-0.08	-0.32	0.04	0.36	0.43	0.03	-0.33	-0.41	0.02	-0.17	1.00	-0.13	-0.01	-0.05	0.24	-0.08	0.11	-0.13
him	0.01	-0.09	0.01	0.10	0.04	-0.10	-0.18	0.41	0.11	0.00	-0.14	0.04	-0.13	1.00	0.05	-0.03	0.12	-0.11	0.00	-0.12
dec	-0.11	-0.10	-0.11	-0.10	-0.05	-0.01	-0.07	-0.04	-0.11	-0.06	0.04	-0.03	-0.01	0.05	1.00	-0.02	0.10	0.13	-0.06	0.00
tri	0.01	0.09	-0.15	-0.09	-0.20	-0.18	-0.12	-0.06	0.14	0.20	0.78	0.35	-0.05	-0.03	-0.02	1.00	-0.08	-0.05	-0.04	-0.04
iso	-0.29	0.13	-0.07	-0.14	0.23	0.20	0.13	-0.05	-0.11	0.03	-0.04	-0.12	0.24	0.12	0.10	-0.08	1.00	0.00	0.11	-0.06
gas	-0.04	-0.14	0.12	-0.03	0.11	-0.02	-0.12	-0.01	-0.01	0.01	-0.04	-0.07	-0.08	-0.11	0.13	-0.05	0.00	1.00	-0.04	0.71
eph	-0.20	0.00	-0.09	-0.08	0.12	0.09	0.06	-0.03	-0.13	-0.03	0.01	-0.07	0.11	0.00	-0.06	-0.04	0.11	-0.04	1.00	-0.03
ven	0.18	-0.11	0.11	0.00	0.04	-0.04	-0.02	-0.01	0.00	0.06	-0.02	-0.05	-0.13	-0.12	0.00	-0.04	-0.06	0.71	-0.03	1.00

Table 4.3 The correlation of physicochemical and biological indices in upper part of Chi river basin

	TEMP	DO	PH	TUR	EC	HAR	ALK	BOD	PO	NO	NH	VE	DIVER	HPI	ASPT
TEMP	1.00	-0.17	0.16	0.16	-0.15	-0.25	-0.18	0.16	0.17	0.24	-0.04	0.07	-0.24	0.10	-0.19
DO	-0.17	1.00	0.25	-0.20	0.09	0.12	0.18	-0.15	-0.16	-0.03	0.01	-0.03	0.11	-0.02	0.16
PH	0.16	0.25	1.00	0.00	0.26	0.25	0.09	0.06	0.01	-0.21	-0.27	-0.09	-0.03	0.23	-0.06
TUR	0.16	-0.20	0.00	1.00	-0.37	-0.49	-0.46	-0.04	0.87	0.26	-0.01	0.40	-0.31	0.08	-0.36
EC	-0.15	0.09	0.26	-0.37	1.00	0.60	0.34	0.23	-0.40	-0.37	-0.19	-0.36	0.24	0.24	0.24
HAR	-0.25	0.12	0.25	-0.49	0.60	1.00	0.68	0.07	-0.53	-0.44	-0.23	-0.33	0.12	-0.10	0.32
ALK	-0.18	0.18	0.09	-0.46	0.34	0.68	1.00	0.12	-0.48	-0.35	-0.14	-0.30	0.09	-0.03	0.36
BOD	0.16	-0.15	0.06	-0.04	0.23	0.07	0.12	1.00	-0.09	-0.02	-0.09	-0.04	-0.03	0.27	0.04
PO	0.17	-0.16	0.01	0.87	-0.40	-0.53	-0.48	-0.09	1.00	0.28	0.21	0.50	-0.34	-0.02	-0.39
NO	0.24	-0.03	-0.21	0.26	-0.37	-0.44	-0.35	-0.02	0.28	1.00	0.14	0.20	-0.21	-0.02	-0.25
NH	-0.04	0.01	-0.27	-0.01	-0.19	-0.23	-0.14	-0.09	0.21	0.14	1.00	0.41	0.23	-0.18	0.05
VE	0.07	-0.03	-0.09	0.40	-0.36	-0.33	-0.30	-0.04	0.50	0.20	0.41	1.00	-0.21	-0.18	-0.34
DIVER	-0.24	0.11	-0.03	-0.31	0.24	0.12	0.09	-0.03	-0.34	-0.21	0.23	-0.21	1.00	0.32	0.52
HPI	0.10	-0.02	0.23	0.08	0.24	-0.10	-0.03	0.27	-0.02	-0.02	-0.18	-0.18	0.32	1.00	0.46
ASPT	-0.19	0.16	-0.06	-0.36	0.24	0.32	0.36	0.04	-0.39	-0.25	0.05	-0.34	0.52	0.46	1.00

The temperature of running waters usually varied on seasonal and daily time scales, and among locations due to climate, elevation, extent of streamside vegetation and the relative importance of ground water inputs (Allan, 1995). Annual fluctuations in stream temperature were very important to stream organisms (Hauer and Lambert, 1996). Many fish in tropical reservoirs such as in Thailand, live at temperatures between 25 - 32°C which was the normal temperature in water resources (ไมตรี ดวงสวัสดิ์ และ จารุวรรณ สมศิริ, 2528). Abel (1996) responded that elevated temperatures had affected aquatic organisms directly, as the organisms responded physiologically or behaviorally to the new conditions and the changed temperature influenced the solubility of oxygen in water. Furthermore, Mason (2002) stated that increasing temperature has declined in species richness of bacteria, benthic inverteberates and zooplankton. The temperature values each sampling sites of the upper part of Chi river basin is shown in Figure 4.1

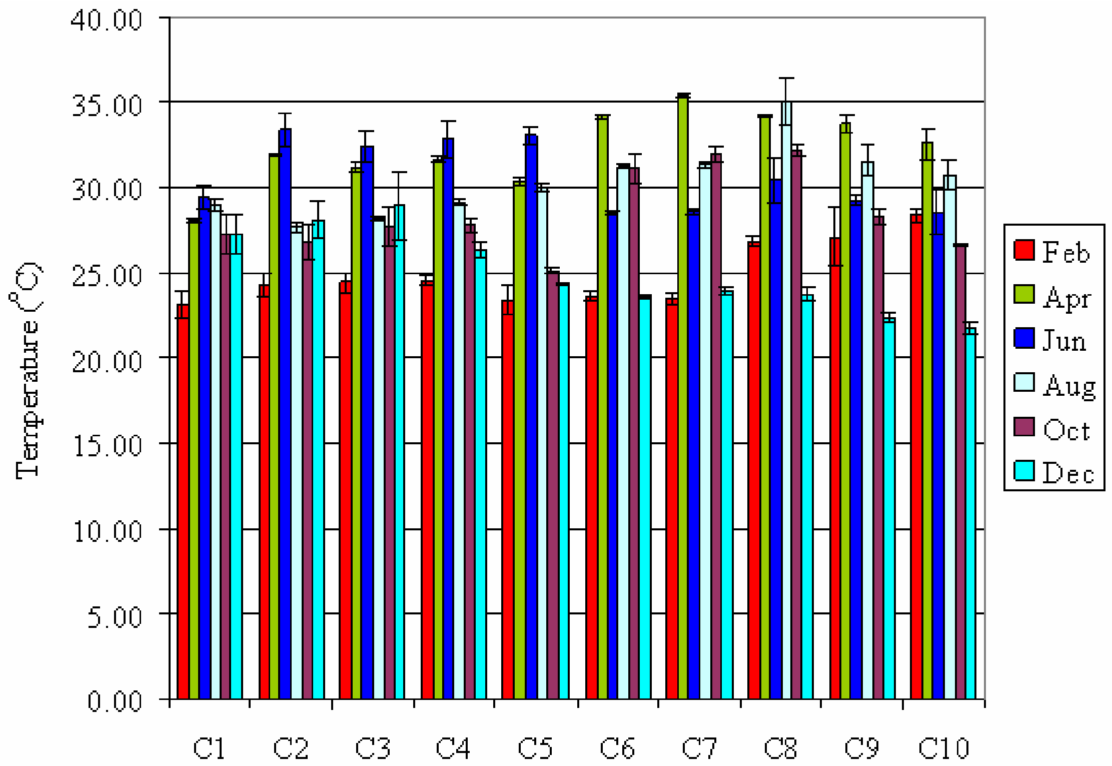

Figure 4.1 Mean of water temperature values (°C) in the upper part of Chi river basin from February to December 2004.

C = sampling sites

4.1.2 Turbidity

The turbidity of the water ranged from 0.40 - 175.67 NTU. The highest level of turbidity was 175.67 NTU at site 10 (Tha Pra) in June 2004, and the lowest in April 2004 at site 1 (Tad Ton). There was no significant different between sites ($p<0.05$). But there was significant between seasons. In the rainy seasons, there was high turbidity when compared to the other seasons because in the rainy season the rainfall and soil erosion increased which caused the high amount of sediment. Indirect effects were mainly due to increased turbidity and the blanketing effect of the particulates when they eventually settle. Increased turbidity will reduce or prevent photosynthesis, leading to a reduction in primary productivity or complete elimination of plants (Abel, 1996). In the winter season and hot season, there was low turbidity, because this season had less water discharge and low velocity which cause the sediment to sink to the substratum of the river. Similarly, Degens et al. (1991, quoted in Dudgeon 1999) revealed that high suspended solids loads during the monsoon increase river turbidity so reducing autochthonous photosynthesis. Moreover, Abel (1996) described that high levels of suspended particulates may interfere with the filter - feeding mechanisms of invertebrates, and possibly the feeding of fish which locate their food visually. In the first site, the turbidity was lower than other sites. Because of this site is the upstream and tributary of Chi river. Thereby, the river had low suspended solids and low turbidity. Likewise, Griffiths (1999) concluded that turbidity, a measure of the concentration of suspended material in the water column that reduces the transparency of the water, generally increased along the length of the water source. The turbidity in each sampling sites of the upper part of Chi river basin is shown in Figure 4.2

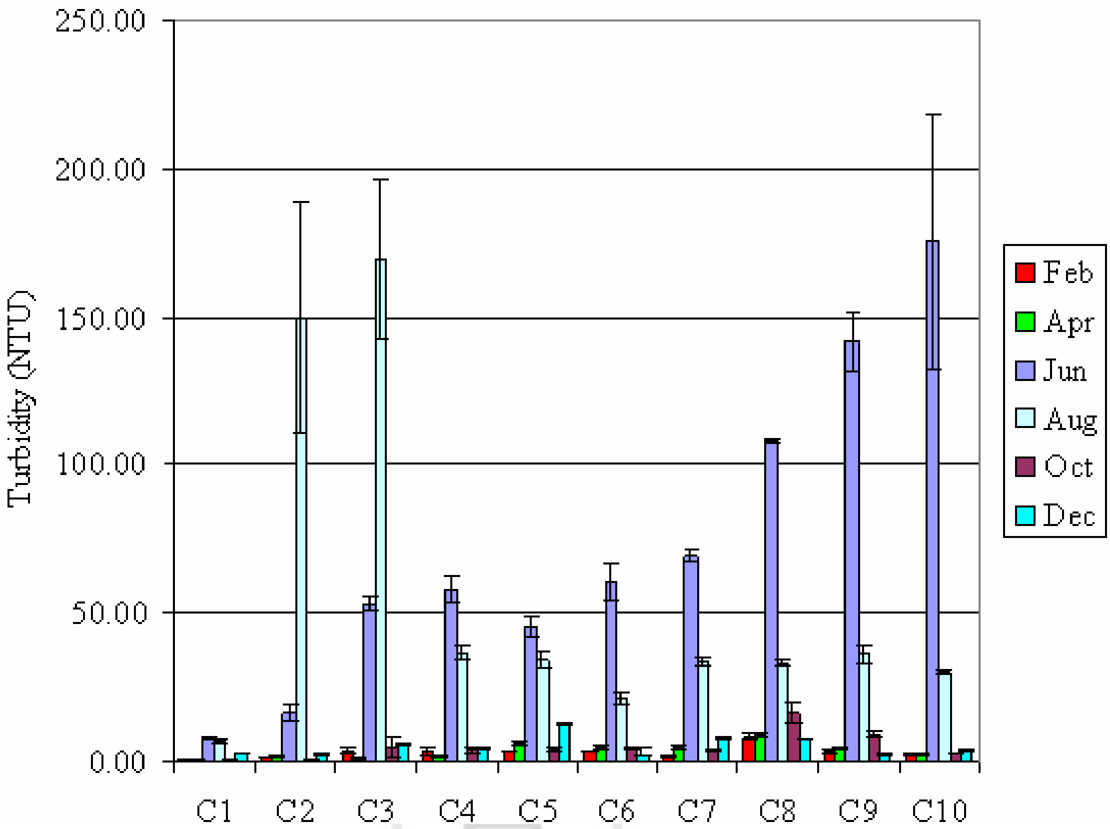

Figure 4.2 Mean of turbidity values (NTU) from the upper part of Chi river basin from February to December 2004

C = sampling sites

4.1.3 Electrical Conductivity

The electrical conductivity of water ranged from 26.12 - 1085.83 µS/cm. The highest value of electrical conductivity was 1085.83 µS/cm at site 6 (Ban Yang Wai) in February 2004. And the lowest value was 26.12 µS/cm at site 1 (Tad Ton) in August 2004. The electrical conductivity values were significantly different between season ($p<0.05$). Majority of the electrical conductivity value tended to be increasing in summer and winter season, and decrease in rainy season. Because of rainfall in the rainy season which increased the amount of water.

The increasing of water in the Chi river caused a dilution of electrolyte because the electrical conductivity related to concentration of ions (มั่นสิน ตัณฑุลเวศม์ และ มั่นรักษ์ ตัณฑุลเวศม์, 2547). The result corresponded to Chiangthong (2005) who found that the electrical conductivity tended to decrease in July and August. Similarly, Pongswat (2002) revealed that the increase of the water in the lake cause a dilution of inorganic substances, ions, minerals and other in the rainy season. Additionally, Tyler (1984, quoted in Dudgeon, 1999) stated that River Kwai was dominated by calcium and bicarbonate ions which reflected the abundance of limestone in the drainage basin, and was characteristic of many Thai rivers. Viner (1987, quoted in Dudgeon, 1999) reported that the electrical conductivity of Purari waters correlated negatively with altitude, and concentrations of several major ions increased downstream. The conductivity declined in Sungai Gomback because of the diluting effects of large volumes of rain (Bishop, 1973a, quoted in. Dudgeon, 1999). Moreover, Allan (1995) concluded that total dissolved salts may decline with increasing discharge which was expected when the input of materials was constant. The electrical conductivity values, each sampling sites of the upper part of Chi river basin is shown in Figure 4.3

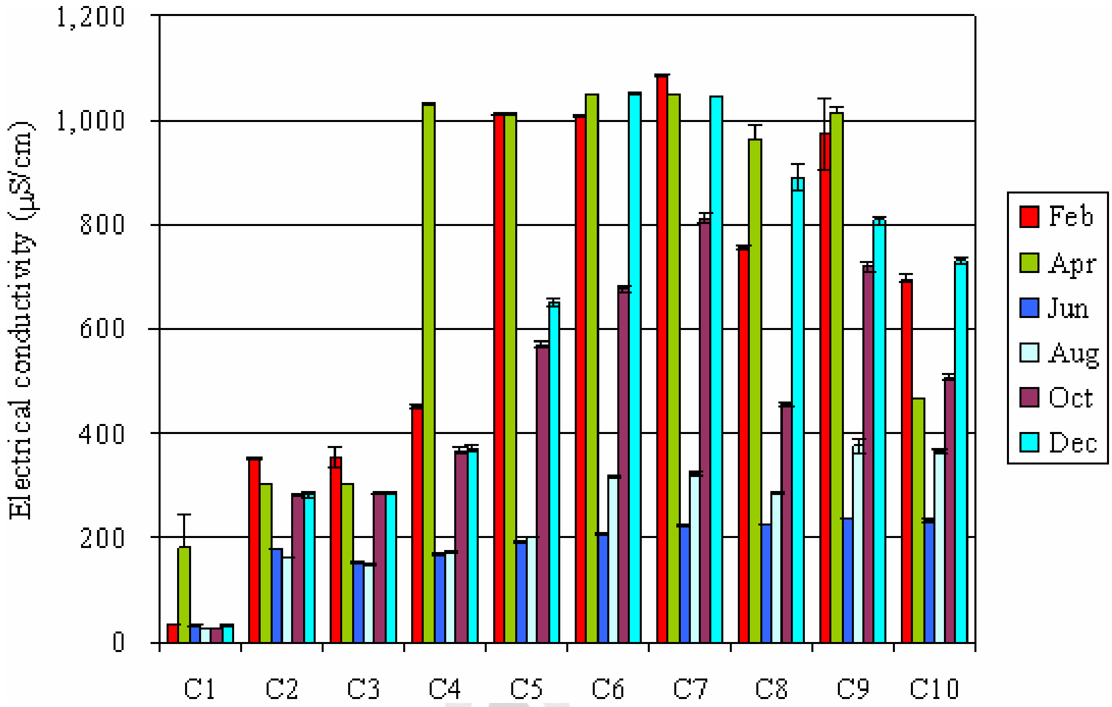

Figure 4.3 Mean of electrical conductivity values (µS/cm) in the upper part of Chi river basin from February to December 2004.

C = sampling sites

4.1.4 Velocity

The velocity of the water varied from 0.03 - 3.02 m/sec. The highest value was 3.02 m/sec in August 2004, at site 2 (Ban Huai Hai) and the lowest in February 2004 at site 6, 8, 9 and 10, April at site 6 and in October 2004. In August, the velocity in all sampling sites was higher than other months. Because there was a high of water discharge due to the effect of having a monsoon climate. There was no significant different between sites ($p<0.05$). But there was significant different between seasons. The rainy season was high velocity. Because there was a high water discharge than other seasons. Sampling site 10 (Tha Phra) had the lowest velocity in every month through the year. Because the upper part of Chi river basin has several dams for irrigation and agriculture. As a result, the speed of water was lower. Furthermore, Chapman (1996) stated that the velocity varied within a day, as well as from day to day and season to season, depending on hydrology influences and the nature of the catchments area. Gordon et al. (2004) stated that the habitats and their habitants varied with patterns of stream flow. Additionally, the velocity and the associated physical forces collectively represent perhaps the most important environmental factor affecting the organisms of running waters (Allan 1995). Similarly, Barnes and Mann (1991) reported that in lotic ecosystems, primary production can be limited by light, flow rate, temperature, and availability of nutrients. Therefore, the organisms showed morphological adaptations such as the presence of hook or sucker for clinging to the substrate (Gordon et al., 2004). The velocity in each sampling sites of the upper part of Chi river basin is shown in Figure 4.4

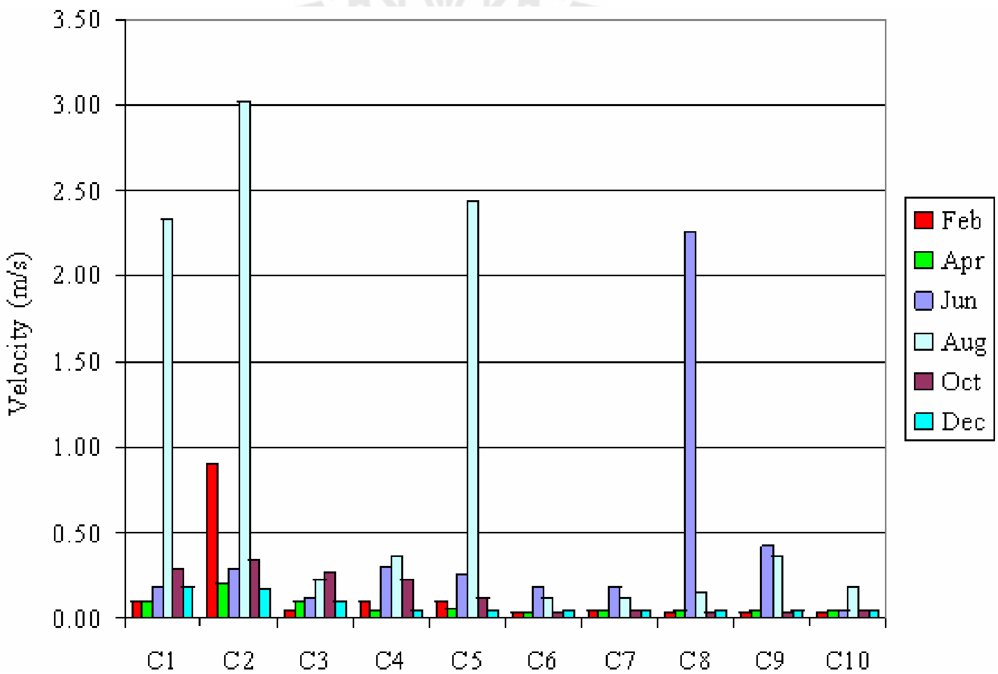

Figure 4.4 Mean of water velocity values (m/s) in the upper part of Chi river basin from February to December 2004.

C = sampling sites

4.1.5 pH

The pH of water samples in the upper part of Chi river basin was between 6.12 - 8.88. The highest pH was 8.88 at site 10 (Tha Phra) in February 2004 and the lowest was 6.12 at site 1 (Tad Ton) in December 2004. The pH of water samples showed little variation between the seasons. There was no significant different between sites and between seasons ($p<0.05$). Unpolluted natural waters showed a pH range from 3.0 - 11.0 or more; those lying between 5.0 and 9.0 generally support a diverse assemblage of species and this range may be considered broadly acceptable (Alabaster and Lloyd, 1980). Similarly, Cole (1983) described that most unpolluted waters, however, exhibit pH values in the ranged 6.0 - 9.0. And, in Thailand, the pH range of surface water quality standard of Thailand is 5.0 to 9.0 (National Environment Board, 1994). The result at site 1 (Ban Tad Ton) was lower than other sites because at Ban Tad Ton is the headwater and covered with extensive trees. The trees take up and store, either in their foliage and wood or in the refractory litter that accumulates under them, much of the small stock of actions in upland soils. In their doing so, hydrogen ions (H^+) must be released to maintain electrical neutrality (Moss, 1998). Generally pH increased from the headwaters to the lower reaches of river systems and from the bottom to the surface of lakes (Ward, 1992). In addition, Jeffries and Mills (1990) described that the small streams draining acid habitats will also be acidic but naturally acidified larger rivers did not occur. Moving water did not accumulate peat or allow the rely - sufficient cycle of pacification to start. However, as rivers moved through a catchments, pH would varied with surrounding geology, soil and landuse between stretches. The pH values, each sampling sites of the upper part of Chi river basin is shown in Figure 4.5

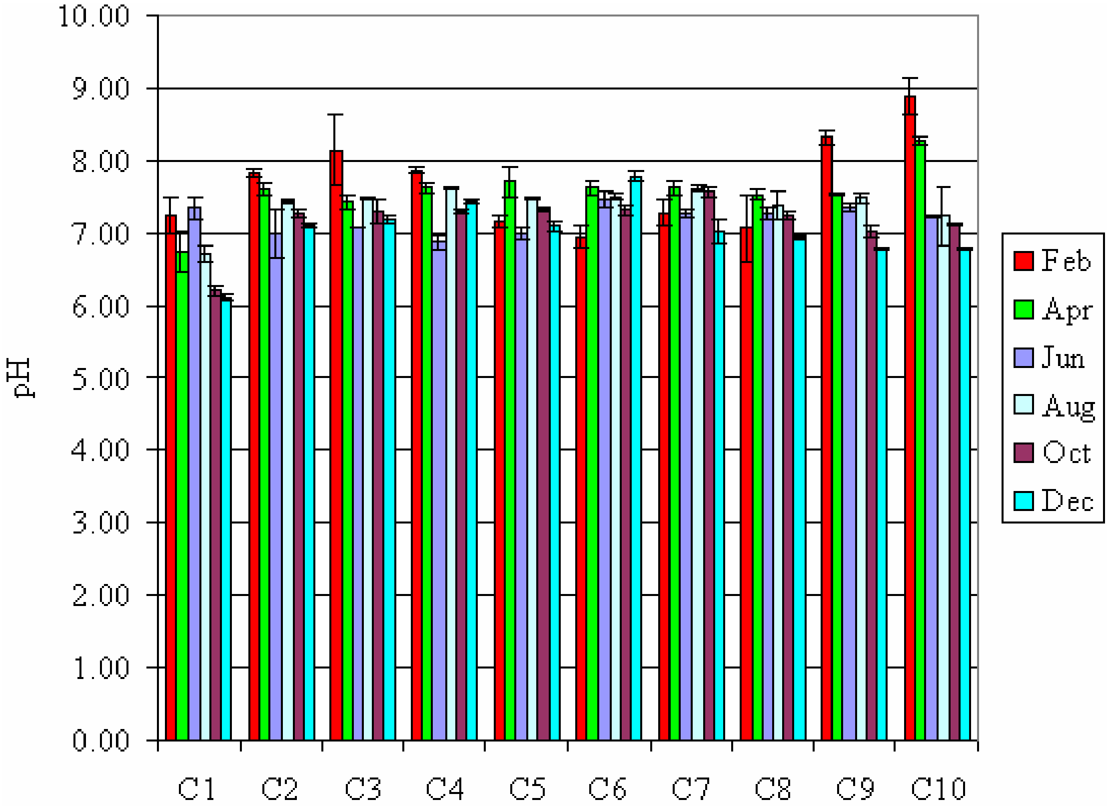

Figure 4.5 Mean of pH values in the upper part of Chi river basin from February to December 2004.

C = sampling sites

4.1.6 Hardness

The water hardness of the upper part of Chi River basin ranged from 53.35 - 243.68 mg/L as $CaCO_3$. The lowest value was 53.35 mg/L as $CaCO_3$ in February 2004 at site 1 (Tad Ton) and the highest value of water hardness was 243.68 mg/L as $CaCO_3$ in December 2004 at site 6 (Ban Khaeng Kam). The results showed statistical differences between sites and seasons ($p<0.05$). Wetzel (2001) reported that the water hardness was governed by the content of calcium and magnesium salts, largely combined with bicarbonate and carbonate and with sulfates, chlorides, and other anions of mineral acids. กรรณิการ์ สิริสิงห์ (2525) stated that water hardness of surface water raged from 80 - 100 mg/L as $CaCO_3$. The water hardness in most natural water came from carbonate and bicarbonate alkalinity. Likewise, Ward (1992) stated that the water hardness values exhibited considerable variation in freshwater, ranging from the extremely soft waters of alpine lakes and streams situated on insoluble bedrock, to the hard waters of calcareous aquatic habitats located in limestone regions. The water hardness of the upper part of Chi river basin was low in rainy season. Because in the rainy season was high amount of rainfall. Therefore, the concentrates of solutions were diluted. Similarly, Chapman (1996) stated that seasonal variation of river water hardness often occurred, reaching the highest values during low flowed conditions and the lowest values during floods. Pongswat (2002) reported that the water hardness was slightly low in the rainy season because the rainfall decreased the dissolved salts and decreased the water hardness. The water hardness had impact on species and abundance of aquatic organisms. Stoner et al. (1984) studied on headwater streams of the River Tywi in west Wales, who found that, where pH was greater than 5.5 and water hardness greater than 8 mg/L as $CaCO_3$, the invertebrate communities consisted of 60 - 78 taxa, whereas in streams with a mean pH less than 5.5 and water hardness less than 10 mg/L as $CaCO_3$, only 23 - 37 invertebrates taxa were presented. Moreover, Neel (1973 quoted in Ward, 1992) reported that mollusks, mayflies, beetles, and dipterans were better developed in the hard, highly alkaline streams; stoneflies and caddish flies were better developed in the soft waters of low alkalinity. มั่นสิน ตัณฑุลเวศม์ และ มั่นรักษ์ ตัณฑุลเวศม์ (2547) reported that the desired water hardness level for most aquaculture species lies no less than 20 mg/L as $CaCO_3$. The water hardness, each sampling sites of the upper part of Chi river basin is shown in Figure 4.6

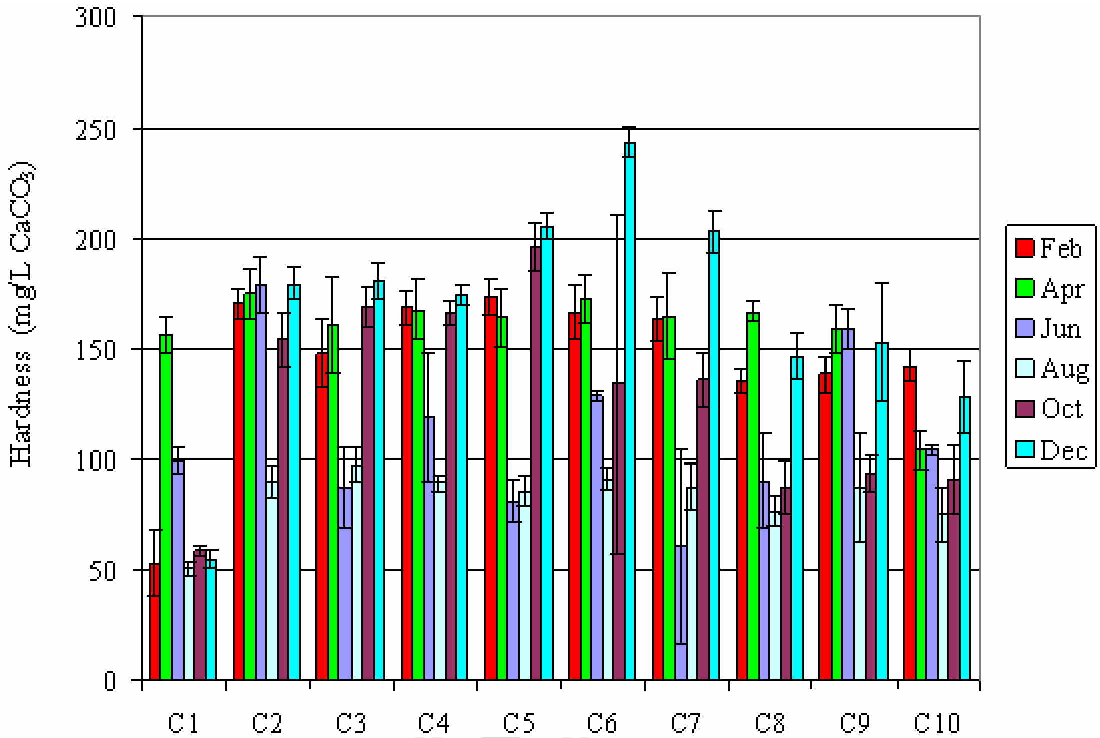

Figure 4.6 Mean of hardness values (mg/ L $CaCO_3$) in the upper part of Chi river basin from February to December 2004.

C = sampling sites

4.1.7 Alkalinity

The alkalinity of the water in the upper part of Chi river basin varied from 14.67 - 38.67 mg/L as $CaCO_3$. The highest value was 38.67 mg/L as $CaCO_3$ in April 2004 at site 6 (Ban Kaeng Kham), and the lowest value was 14.67 mg/L as $CaCO_3$ in August 2004 at site 9 (Ban Non Som Boon). The alkalinity values were significant between seasons ($p<0.05$). But there was no difference between sampling sites. Typically, carbonate (CO_3^{2-}), bicarbonate (HCO_3^{-}) and hydroxide (OH^{-}) but might consist of a little silicate, phosphate, borate, fluoride, arsenate, aluminates, and other organic matter (ชาญยุทธ คงภิรมย์ชื่น, 2533). Two sources of carbonate and bicarbonate were rainfall and soil (Chapman, 1996). The values were high in cold season and hot season. On the other hand, low in rainy season. Because in the rainy season was high amount of rainfall. Therefore, the concentrations of solutions were diluted. Similarly, Pongswat (2002) reported that the alkalinity was high in February and fluctuated throughout the investigation. At site1 (Tad Ton), the alkalinity values were lower than other sampling sites. Because of this sampling site was covered with bamboo forest. So, the water had several weak acids such as humic and fulmic acid. Therefore, the alkalinity was low in this sampling site. Most aquatic organisms can live in a broad range of alkalinity concentrations. The desired total alkalinity level for most aquaculture species lies between 50 - 150 mg/L as $CaCO_3$, but no less than 20 mg/L as $CaCO_3$ (Wurts, www, 2006). Furthermore, Ward (1992) concluded that the densities of Trichoptera and Ephemeroptera exhibited significant positive and negative correlations, whereas densities of Dipteral and Coleopteran were not significantly correlated with alkalinity. The alkalinity values in each sampling site of the upper part of Chi river basin is shown in Figure 4.7

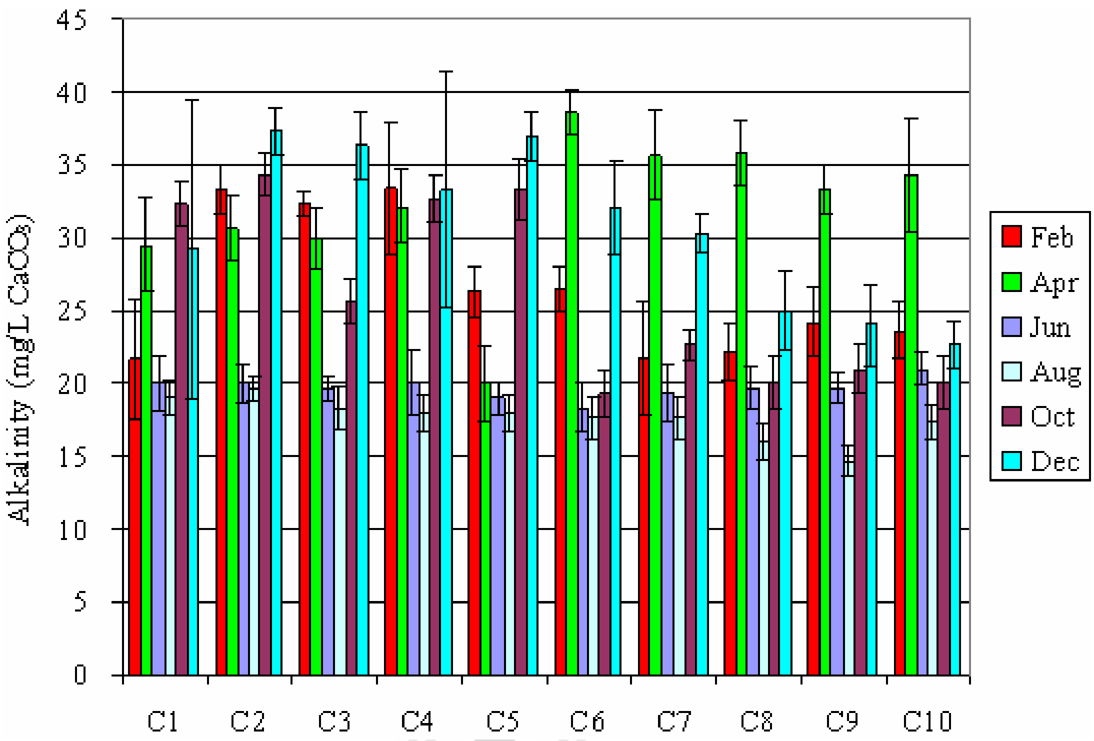

Figure 4.7 Mean of alkalinity values (mg/L $CaCO_3$) in the upper part of Chi river basin from February to December 2004.

C = sampling sites

4.1.8 Dissolved Oxygen (DO)

The dissolved oxygen of water samples in the upper part of Chi river basin varied from 3.41 - 8.34 mg/L. The lowest level was 3.41 mg/L in June 2004, and the highest was 8.34 mg/L in February 2004 at site 7 (Ban Yang Wai). There was no significant different between sites but there was significant between seasons ($p<0.05$). The highest dissolved oxygen was presented at site 6 in the late winter season. And, the lowest dissolved oxygen was measured at site 6 in rainy season. Because the main sources of dissolved oxygen are the atmosphere and photosynthesis by aquatic plants.

The solubility of oxygen is a function of water temperature, pressure, and salinity of water, temperature, pressure, and salinity. Cold water holds more oxygen at saturation than warm water (Ward, 1992). Therefore, the dissolved oxygen increased in cold season. In addition, oxygen from photosynthesis increased the amount of oxygen in the watercourses. In the rainy season, the dissolved oxygen decreased because the rainfall washed down the soil and the nutrients from the watershed into the watercourses. Then, the turbidity of water was increased and a depletion of dissolved oxygen in the water. Similarly, Chiangthong (2005) who found that the highest score was revealed in the cool dry season and the lowest dissolved oxygen was measured in the rainy season. Furthermore, Pongswat (2002) who found that the amount of oxygen decrease slightly in the rainy season because of the increase in precipitation in the rainy season which washed down the soil and the nutrients from the land into the water resources. These finding corresponded to the reported of Gordon, McMathew and Finlayson (2004) found that in the turbulent, well - mixed waters of upland streams, dissolved oxygen concentrations are usually near saturation levels. As these turbulent reaches gradually give way to more poorly mixed waters downstream. Additionally, Chapman (1996) stated that determination of dissolved oxygen concentrations is a fundamental part of a water quality assessment since oxygen is involved in, or influences, nearly all chemical and biological processes within water bodies. Concentration below 5 mg/L may adversely affect the functioning and survival of biological communities and below 2 mg/L may lead to the death of most fish. Similarly, มั่นสิน ตัณฑุลเวศม์ และ มั่นรักษ์ ตัณฑุลเวศม์, 2547) reported that in general the optimum of dissolved oxygen value of 5 mg/L was suitable for living organism in the water, but dissolved oxygen at a low of 3 mg/L was dangerous for living organisms in the water. The dissolved oxygen values in each sampling sites of the upper part of Chi river basin is shown in Figure 4.8

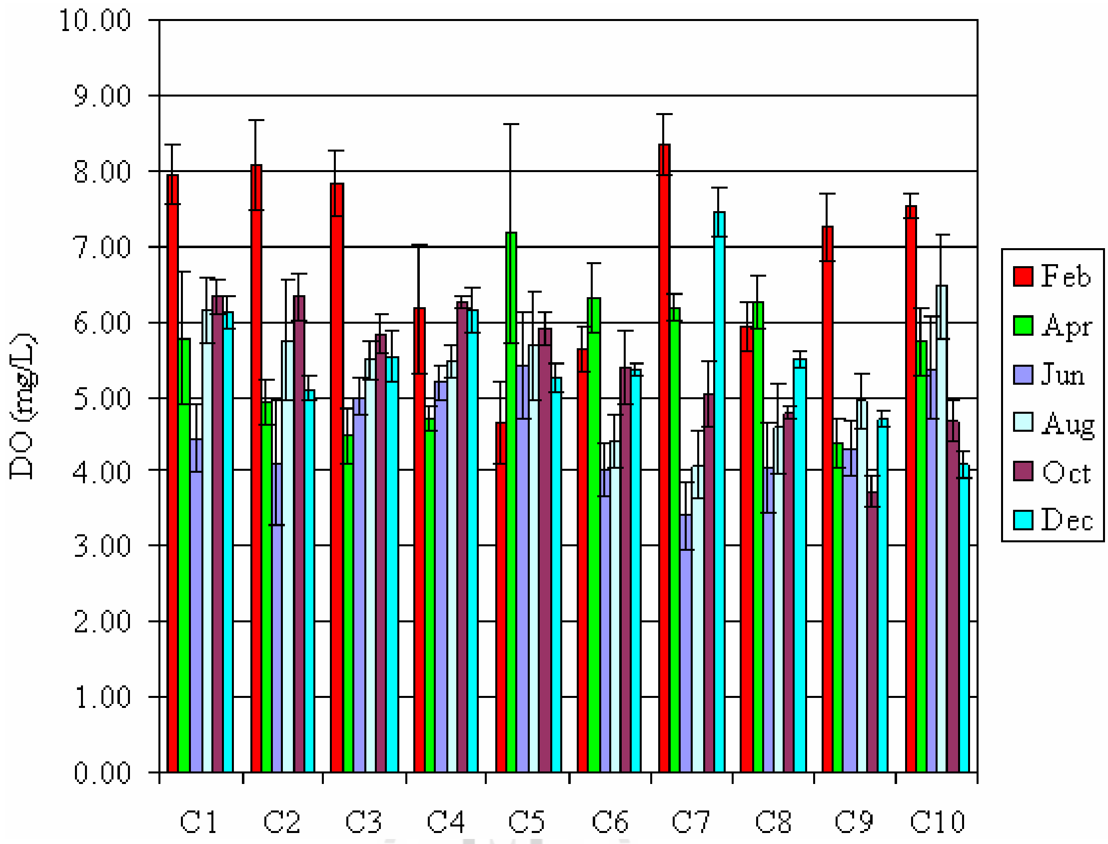

Figure 4.8 Mean of dissolved oxygen values (mg/ L) in the upper part of Chi river basin from February to December 2004.

C = sampling sites

4.1.9 Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand is an approximate measure of the amount of biochemically degradable organic matter present in a water sample. It is defined by the amount of oxygen required for the aerobic microorganisms present in the sample to oxidize the organic matter to a stable inorganic form (Chapman, 1996). The biochemical oxygen demand of water samples in the upper part of Chi river basin ranged form 0.38 - 5.48 mg/L. The lowest value was 0.38 mg/L in October 2004 at site 2 (Ban Huai Hai) and the highest value was 5.48 mg/L. at site 10 (Tha Pra). The results showed statistical differences between seasons but there was no difference between sampling sites ($p<0.05$). The amount of biochemical oxygen demand increased slightly from site 1 (Tad Ton) to site 10 (Tha Pra). The biochemical oxygen demand of Tad Ton sampling site was lower than other sampling sites. But Tha Pra sampling site was higher than the other sampling sites. Then,Tad Ton is the upstream and Tha Pra is the down stream. Therefore, Tad Tod was low organic substances and Tha Pra was high amount of organic substances. This result corresponded to the study of, วิไลลักษณ์ กิจจนะพานิช (2536) pointed out that the biochemical oxygen demand showed the level of contamination or waste water by organic substances. If the water has high levels of biochemical oxygen demand, it showed there was a corresponding high level of organic substances in the water. The biochemical oxygen demand was value of oxygen demand to be used by bacteria for organic matter degradation in water. The biochemical oxygen demand was an indicator that present decay level of water sources. In case water sources needed high oxygen, it showed that there were many decayed organic substances which had to use many oxygen for degradation process resulting in the lack of oxygen in water sources (ไมตรี ดวงสวัสดิ์ และ จารุวรรณ สมศิริ, 2528). Furthermore, Griffiths (1999) supported that organic substances, however, showed the reverse trend with low concentration in creeks and higher concentration down stream. For that reason, the biochemical oxygen demand was low in upstream and high in down stream. Additionally, at the downstream has several check dam and fish farming. Mason (2002) reported that fish farming may also result in a deterioration of water quality down stream. Effluents leaving the farm were high in suspended solids, BOD, ammonia and nutrients from faces and excess food. The biochemical oxygen demand each sampling sites of the upper part of Chi river basin is shown in Figure 4.9

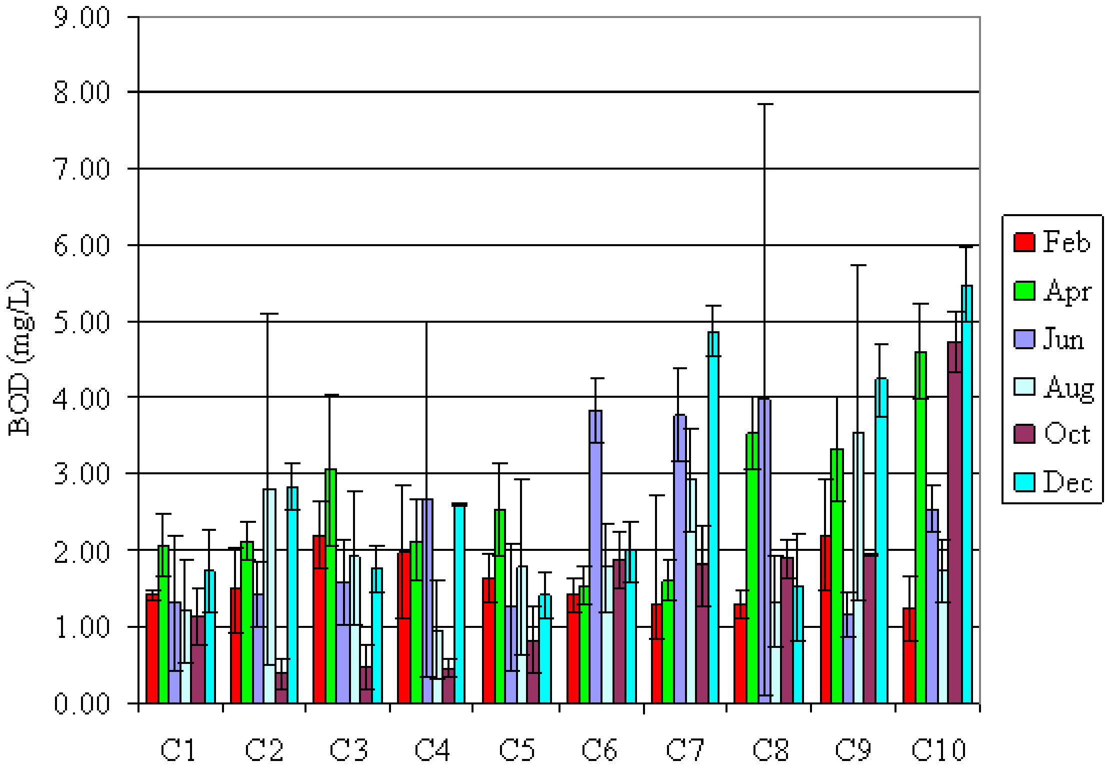

Figure 4.9 Mean of biochemical oxygen demand values (mg/L) in the upper part of Chi river basin from February to December 2004.

C = sampling sites

4.1.10 Phosphate

The concentration of phosphate values varied from non - detected - 0.09 mg/L. The highest value was 0.09 mg/L in August 2004 at site 2 (Ban Huai Hai) and in June 2004 at site 9 (Ban Non Som Boon). The phosphate concentration was not significant in the sampling sites but there was significant different between seasons ($p<0.05$). The concentration of phosphate was low in all sampling sites throughout the year. Natural sources of phosphate were mainly the weathering of phosphorus - bearing rocks and the decomposition of organic matter. Domestic wastewater, industrial effluents and fertilizer runoff contribute to elevated levels in surface waters (Chapman 1996). Merbeck (1982) reported that dissolved in organic phosphorus, commonly referred to as orthophosphate average about 10 μg/L worldwide among unpolluted rivers. Total dissolved phosphorus in there waters were very low, around 0.01 mg/L for PO_4^{3-} and 0.025 mg/L for total dissolved phosphate, which includes the organic form. Similarly, Moss (1988, quoted in Abel, 1996) who stated that the levels normally found in unpolluted waters, which ranged from about 0.001 - 1.00 mg/L. Additionally, Chapman (1996) reported that in most natural surface waters, phosphorus ranged from 0.005 - 0.020 mg/L. Concentrations as low as 0.001 mg/L may be found in some pristine waters and as high as 200 mg/L in some enclosed saline water. This result the concentration was low in cold season and summer season, On the other hand, high in rainy season. Principally, nutrient concentrations often varied seasonally due to influenced of hydrology, the growing season and changed in anthropogenic inputs (Allan, 1995). In rainy season, a large amount of rainfall flushed materials from the surrounding terrestrial soils, including agricultural fertilizers, as apparently was true for phosphate in the drainage area, concentrations increase at high flows. มั่นสิน ตัณฑุลเวศม์ และ มั่นรักษ์ ตัณฑุลเวศม์ (2547) reported that the concentration of total phosphorus ranged from 0.05 - 0.1 mg/L could be affected. The concentration of phosphate in each sampling sites of the upper part of Chi river basin is shown in Figure 4.10

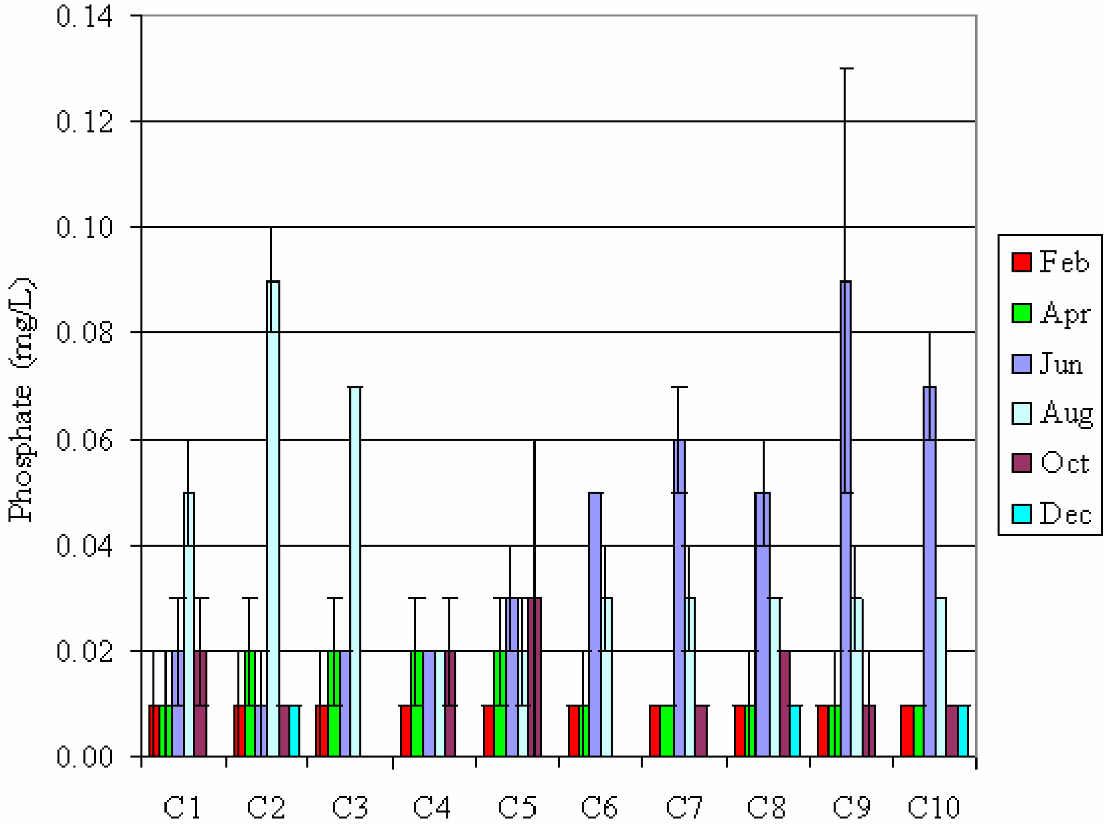

Figure 4.10 Mean of phosphate values (mg/L) in the upper part of Chi river basin from February to December 2004.

C = sampling sites December

4.1.11 Nitrate

The nitrate concentration values of the upper part of Chi river basin ranged from 0.08 - 0.38 mg/L the highest value was 0.38 mg/L in December 2004 at site 1 (Tad Ton). On the other hand, the lowest value was 0.08 mg/L in February 2004 at site 5 (Ban Khai). Horne and Goldman (1994) who stated that the major sources of nitrates in streams and rivers were runoff from agriculture and domestic discharges from urban. The results showed statistical differences between seasons but there was no difference between sampling sites ($p<0.05$). The concentrations of nitrate values was high in rainy season. This result corresponded to the research of Pongswat (2004) who reported that the amount of nitrate - nitrogen reached its highest figure in rainy season. In addition, the rainfall flushed nitrate from the land around the lake into the lake. Similarly, Allan (1995) who reported that the heavy rainfall flushed nutrients from the riparian area, including agriculture fertilizers into the rivers. So the concentrations of nitrate was high at high flow. Merbeck (1982, quoted in Wetzel, 2001) reported that in subarctic and in Amazonian, nitrate concentrations ranged from (25µg/L) to 200 µg/L in some temperate rivers. Higher nitrate concentrations were found among rivers influenced by agricultural runoff. Likewise, Chapman (1996) pointed out that the nitrate concentrations of surface water was less than 1 mg/L. When concentration is excess 5 mg/L indicated pollution by human or animal waste or fertilizer runoff มั่นสิน ตัณฑุลเวศม์ และ มั่นรักษ์ ตัณฑุลเวศม์ (2547) reported that the nitrate concentration of surface water varied from 1 - 5 mg/L. The nitrate concentrations values did not exceed 5 mg/L, the maximum figure set as the standard of surface water quality in Thailand set by National Environmental Board, (1994). The nitrate concentrations in each sampling sites is shown in Figure 4.11

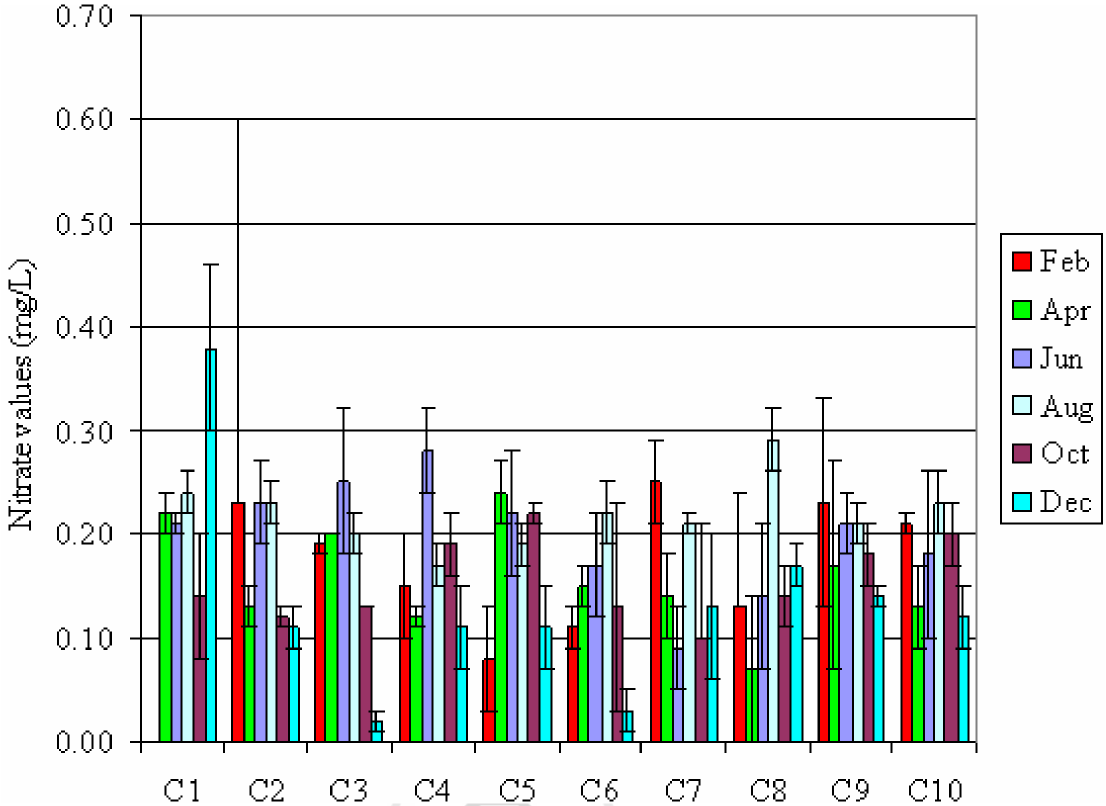

Figure 4.11 Mean of nitrate values (mg/L) in the upper part of Chi river basin from February to December 2004.

C = sampling sites

4.1.12 Ammonia

The concentrations of ammonia ranged from 0.02 - 0.36 mg/L. The highest level ammonia was 0.36 mg/L in August 2004 at site 2 (Ban Huai Hai). On the other hand, the lowest value was 0.02 mg/L in February 2004 at site 1 (Ban Tad Ton). The concentrations of ammonia was low all sampling sites throughout the investigation. Therein, Chapman (1996) stated that natural waters contained small amounts of ammonia and ammonia compounds, usually less than 0.1 mg/L. Higher concentrations was cause from domestic sewage, industrial water and fertilizer runoff. Merbeck (1982, quoted in Wetzel, 2001) stated that ammonia concentrations varied from 7 - 60 μg/L in natural waters, as was the condition in aerobic waters of reservoirs and lakes. The concentrations of ammonia was no significant different between sampling sites ($p<0.05$). Conversely, there was different between sampling sites. This results the concentrations of ammonia was low in the rainy season but was high in the cold season. Similarly, Horne and Goldman (1994) reported that at autumn overturn, ammonia levels rise considerably but then fell. In cold season, ammonia may increase to very high levels (>1 mg/L), particularly under ice. Furthermore, McClain et al. (1994 quoted in Wetzel 2001) described that the activity of terrestrial vegetation of the riparian zones influenced the loadings of nitrate and ammonia to the rivers; nitrogen concentrations were general higher during periods of vegetation dormancy or following losses from harvesting or fire. However, Horne and Goldman (1994) stated that sometimes, flooded streams and rivers contain a large amount of ammonia because there were no sites for uptake or microbial transformation of ammonia to nitrate. The standard surface water quality of Thailand which must not exceed 0.5 mg/L set by the National Environmental Board in 1994. This finding did not exceed the water quality of Thailand. The concentrations of ammonia each sampling site of the upper part of Chi river basin is shown in Figure 4.12

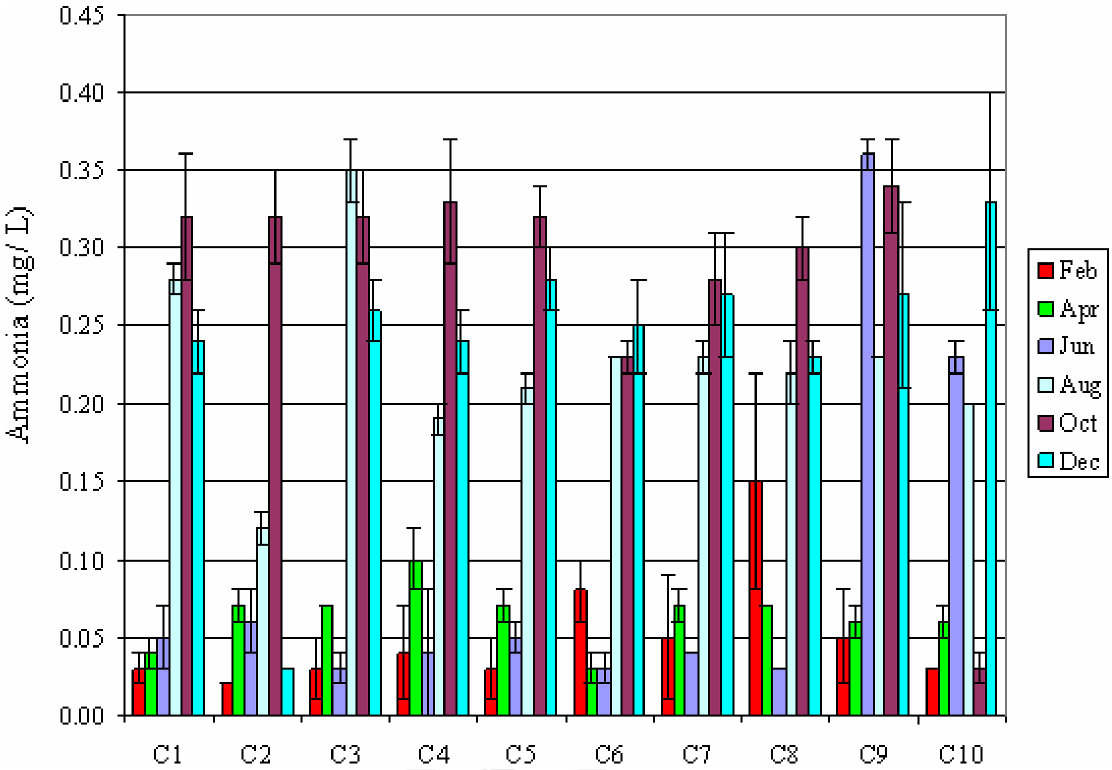

Figure 4.12 Mean of ammonia values (mg/L) in upper part of Chi river basin from February to December 2004.

C = sampling sites

4.2 Biological properties

4.2.1 Benthic macroinvertebrates

The study of the benthic macroinvertebrates were conducted in order to monitor water quality in the upper part of Chi river basin form February 2004 to December 2004. Benthic macroinvertebrates were collected 6 times from 10 sampling sites. The results showed that there were 8 orders/classes, 25 families 1,861 individuals. The Odonata was the most abundant order with 10 families 1,322 individuals approximately 71.08% of the total macroinvertebrates. There were 4 families of Hemiptera of the total macroinvertebrates (about 24.03%). There were 2 families of Isopoda of the total macroinvertebrates (about 1.94%). There was 1 family of Decapoda of the total macroinvertebrates (about 1.83%). There were 2 families of Gastropoda of the total macroinvertebrates (about 0.59%). There were 2 families of Ephemeroptera of the total macroinvertebrates (about 0.32%). There was 1 family of Veneroida of the total macroinvertrates (about 0.16%). There was 1family of Trichoptera of the total macroinvertebrates (about 0.05%) (Figure 4.13). The highest number of macroinvertebrates (258 individuals) was found at sampling site 3 (Ban Non Pluai). On the other hand, the lowest number of macroinvertebrates (145 individuals) was found at sampling site 4 (Ban Non Po) (Figure 4.13). Because of Ban Non Pluai sampling site was covered with small grass and shrub, although there were several habitats with aquatic plants. Therefore, abundant of benthic macroinvertebrates were presented. Ban Non Pho sampling site was covered with small plants and some parts were soil erosion. The most substrates of this sampling site were sand. Wallace and Anderson (1996) supported that sandy substrate of rivers or streams were poor habitats because the shifting nature of the bed affords unsuitable attachment sites and poor food conditions. Similarly, Williams and Feltmate (1992) stated that sandy substrates represent poor habitats because they hold little in the way of organic matter and were unstable. December 2004 was the highest abundant of macroinvertebrates. On the other hand, the lowest, was August 2004. This result responded to the reported of Pahwa (1979), quoted in Dudgeon, 1999) reported that the tendency of zoobenthos abundance to peak in the winter - summer interphase and decline during the rainy season appears to be a general and rivers in tropical Asian. Likewise, Ray et al. (1966, quoted in Dudgeon, 1999) stated that zoobenthos population peak in early summer before the floods were lowest during the summer monsoon.

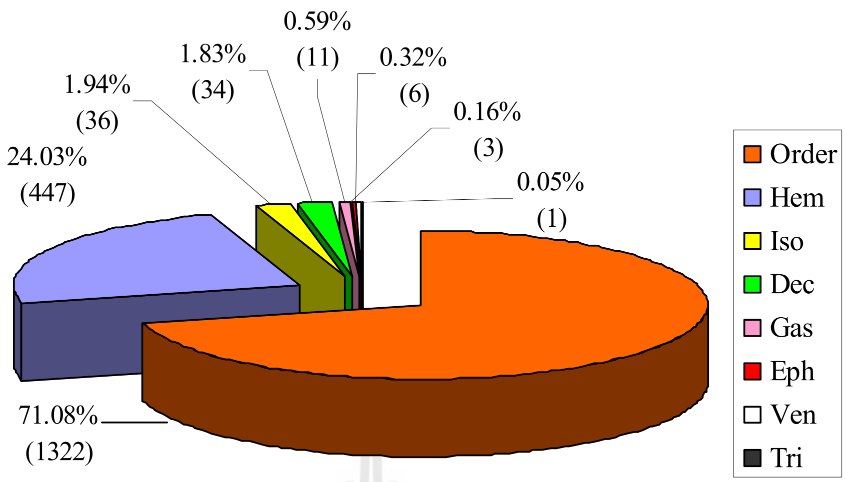

Figure 4.13 The percentage of each macroinvertebrate order of the upper part of Chi river basin.

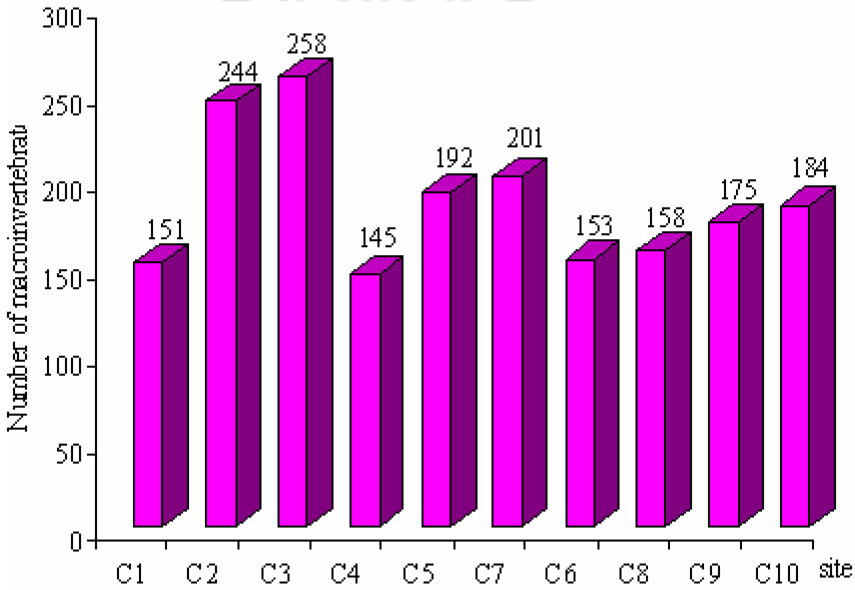

Figure 4.14 The number of macroinvertebrates in each sampling site of the upper part of Chi river basin from February to December 2004

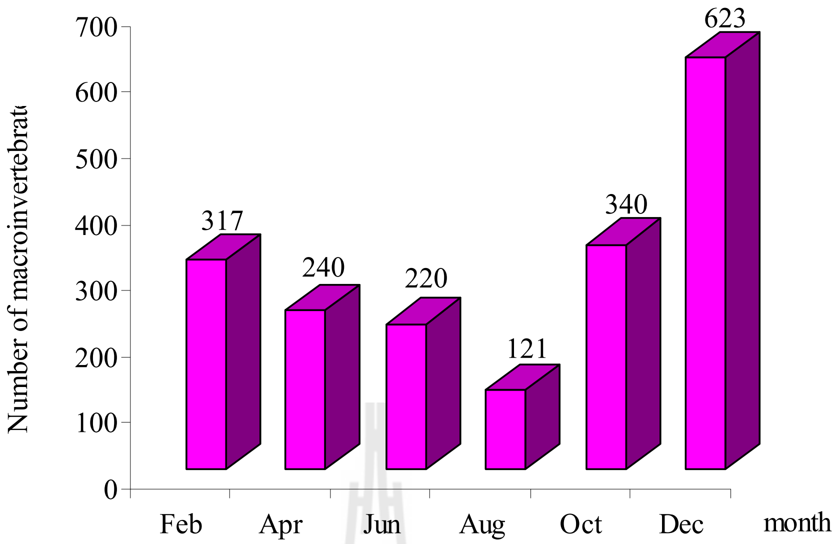

Figure 4.15 The number of macroinvertebrates in each month of the upper part of Chi river basin from February to December 2004

4.2.2 HBI Index

The HBI index values ranged from 2.33 - 6.89. The highest was 6.89 at site 5 in June 2004. On the other hand, the lowest value was 2.33 at site 1 in April 2004. (Table 1 E). There was no significant different between sites and seasons (P<0.05). The HBI scores revealed water quality from poor to excellent. The water quality at site 1 and site 2 was good to excellent and site 8 to site 10 was poor to good. The HBI index scores agreed with the water quality assessed by physicochemical parameters. The HBI index values were low in December and high in summer. Because in summer organism present during the summer months generally tend to be more tolerant than other season.

4.2.3 BMWP^{Thai} Score and ASPT

The ASPT score varied from 3.90 - 7.30. The highest value was 7.30 at site 3 in February and the lowest value was 3.90 at site 3 in June (Table 1 E). Because rainy season had some tolerant families. The water quality was fairly poor to fairly good. There was no significant different between sites and seasons ($p<0.05$). The ASPT index agreed with the water quality assessed by physicochemicals parameters. สารสิน อุยยานนท์, ยรรยง อินทร์ม่วง และวงศ์วิวรรธ์ ธนูศิลป์ (www, 2539) reported that BMWP and ASPT performed effectively superior to the physicochemicals in evaluating river water quality status. Furthermore, Chiangthong (2005) reported that the ASPT scores were high in rainy season (June) and low in hot season (May).

4.2.4 Diversity Index

This study, the diversity index was calculated by using Shannon - Wiener Index. The diversity in ranged from 0.21 - 1.91. The highest value was 1.91 at site 1 in August 2004. On the other hand the lowest value was 0.21 at site 5 in December (Table 1 E). The water quality in range from polluted to moderate pollution. The results showed that in February the water quality was moderate pollution. Conversely, the water quality in June 2004 at all sampling sites mere polluted. สารสิน อุยยานนท์, ยรรยง อินทร์ม่วง และวงศ์วิวรรธ ธนูศิลป์ (www, 2539) reported that the diversity index was high sentiently and high efficiency. This study, the values of diversity index did not agree with the water quality assessed by physicochemical parameters. Moreover, Washington (1984, quoted in Griffiths, 1999) reported that the diversity index was dismissed as a measure of water quality because it failed to correlate well with chemical variables associated with pollution. Today diversity indices have been essentially replaced with simplified measure of community structure: taxa richness and EPT richness. Lenat (1988 quoted in Griffith, 1999).

4.2.5 Data Analysis

This research was analyzed by using multivariate statistical package. The hierarchical cluster analysis was used in grouping the sampling site. By using physicochemical factors, the results showed the cluster fell into 4 groups (Figure 4.16). The first group had 19 sampling sites namely, site 2 in December, site 3 in December and site 4 in February. The second group had 19 sampling sites such as, site 1 in October and site 7 in June. The third group had 12 sampling site such as site 8 in April, site 9 in February and site 7 in December. The fourth had 10 sampling sites such as site 5 in October, site 5 in December and site 8 in December. And, the grouping by using benthic macroinvertebrates could be classified into 3 groups (Figure 4.17). The first group had 32 sampling sites such as site 9 in December, site 9 in October and site 4 October. The second group had 27 sampling sites such as site 1 in August, site 6 in February and site 7 in December. Factor analysis by using PCA analysis technique was used to analysis the correlation between benthic macroinvertebrate orders to water quality. The results showed 4 major clusters, the first cluster consist of ammonia and Trichoptera, the third cluster consist of alkalinity and hardness, the last cluster consist of electrical conductivity, biochemical oxygen demand and temperature (Figure 4.18). The PCA analysis showed the correlation between physicochemical factors and biological indices. The results showed tree major clusters, the first cluster consist of electrical conductivity, hardness, alkalinity index, the second consist of temperature, pH, biochemical oxygen demand and HBI index, the last cluster consist of turbidity, phosphate, nitrate and velocity (Figure 4.19).

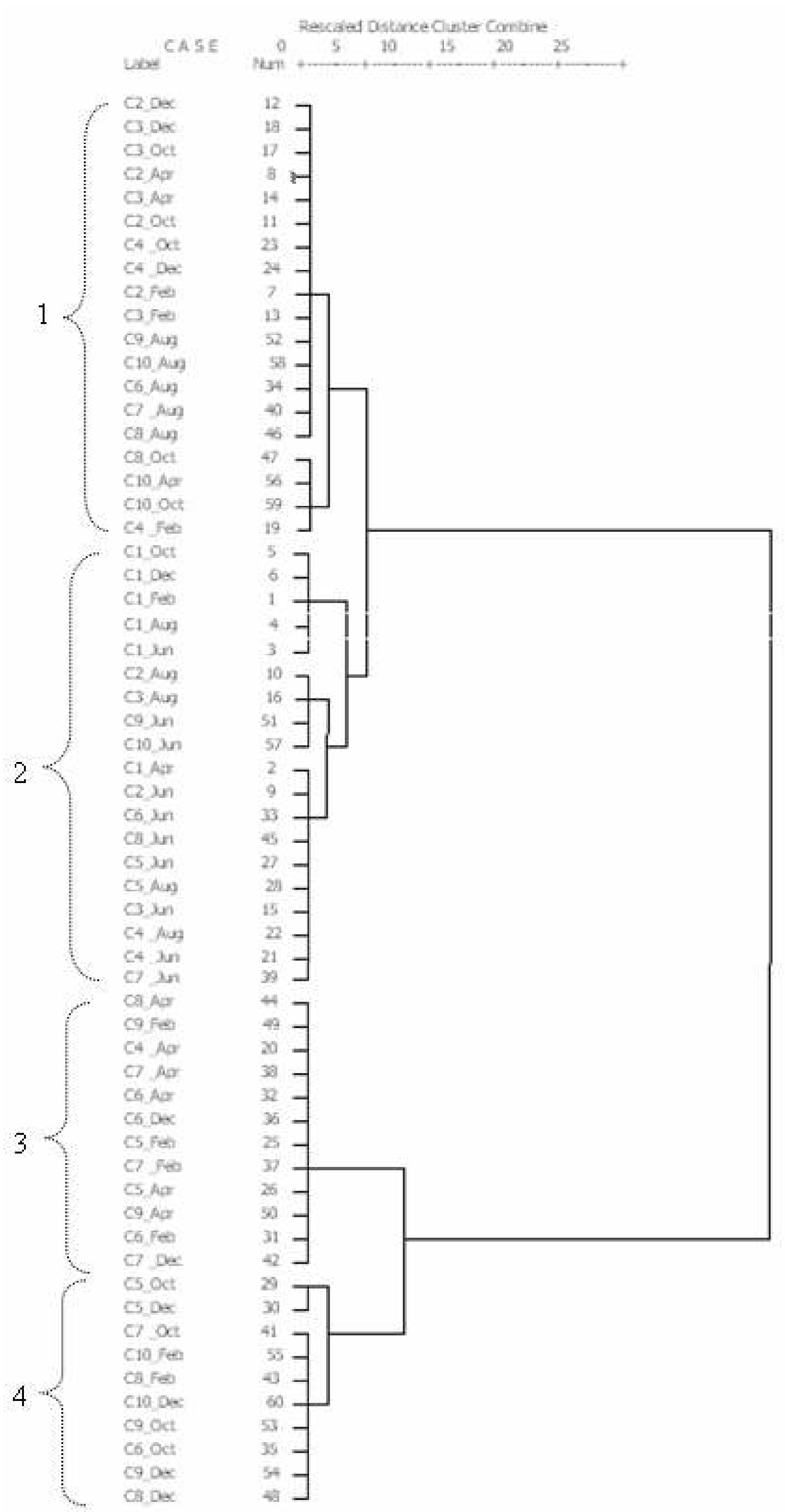

Figure 4.16 Dendrogram of sampling sites by using physicochemical factors of the upper part of Chi river basin

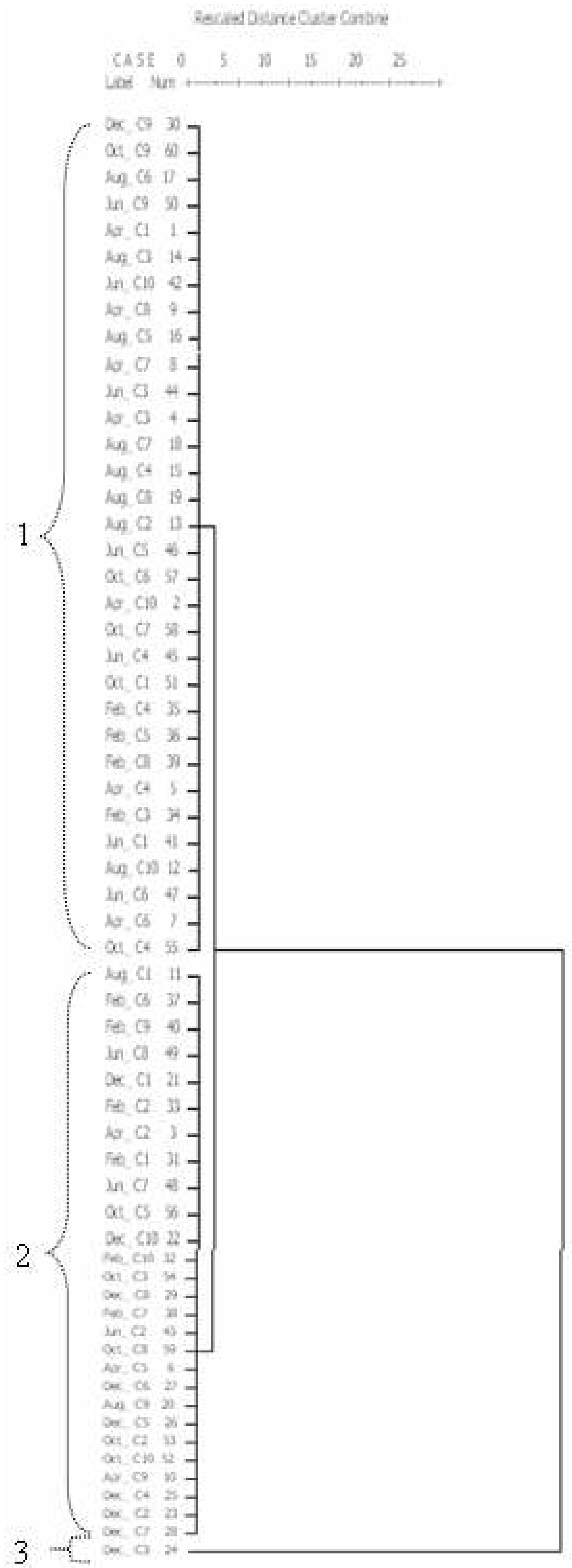

Figure 4.17 Dendrogram of sampling sites by using benthic macroinvertebrates of the upper part of Chi river basin

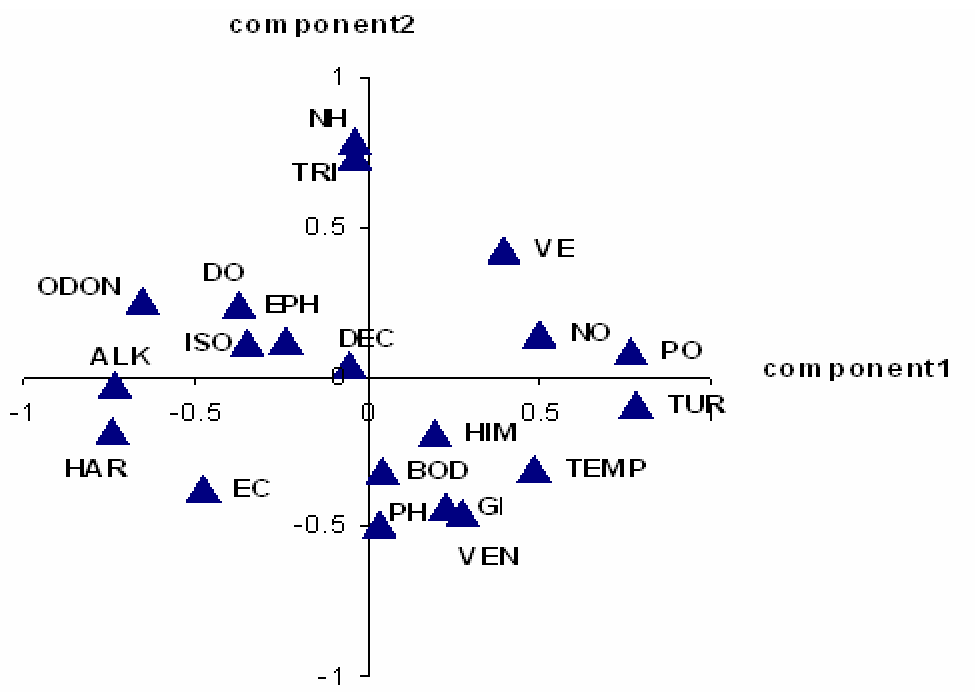

Figure 4.18 The correlation between physicochemical factors and benthic macroinvertebrate orders in the upper part of Chi river basin

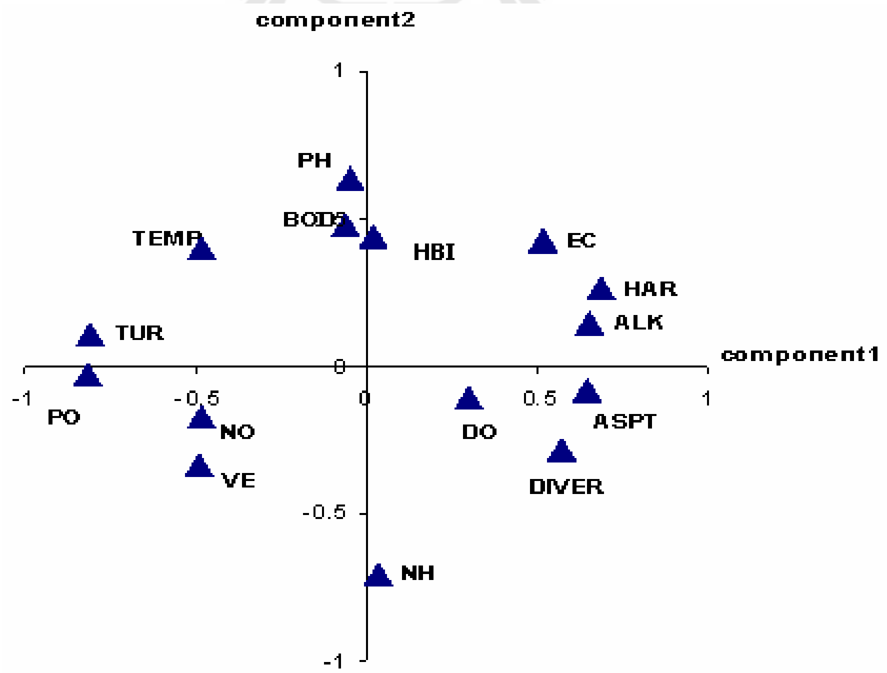

Figure 4.19 The correlation between physicochemical factors and biological indices in the upper part of Chi river basin

CHAPTER V

CONCLUSION

This research was a study of water quality using physicochemical and benthic macroinvertebrates in the upper part of Chi river basin from February 2004 to December 2004. The objectives of the study were : (1) To monitor and assess water quality using physicochemical measurements and benthic macroinvertebrates in the upper part of Chi river basin (2) To examine the correlation between water quality and benthic macroinvertebrates in the upper part of Chi river basin (3) To study type diversity of benthic macroinvertebrates in the upper part of Chi river basin. The water samples were collected and analyzed in laboratory bimonthly from February 2004 to December 2004. The conclusions of this study were as follows :

1. The study of the physicochemical factors of water quality

The water temperature ranged from 23.12 - 35.33°C. The turbidity varied from 0.40 - 175.67 NTU. The electrical conductivity ranged between 26.12 - 1085.83 µS/cm. The water velocity varied from 0.03 - 3.02 m/sec. The pH of water samples ranged from 6.12 - 8.88. The hardness of water samples fluctuated from 53.35 - 243.68 mg/L as CaCO3. The alkalinity ranged from 14.67 - 38.67 mg/L as CaCO3. Dissolved oxygen of water samples ranged from 3.41 - 8.34 mg/L.Biochemical oxygen demand of water samples varied from 0.38 - 5.48 mg/L. Thephosphate ranged from non - detected - 0.09 mg/L. The nitrate varied from 0.08 - 0.38 mg/L and the ammonia ranged from 0.02 - 0.36 mg/L. Using the water quality to compare with the Water Quality Standard of Thailand using dissolved oxygen parameter, the upper part of Chi river basin was classified into 2 groups. Site 1 was classified in class 2 with very clean freshwater resources. Site 2 to 10 were classified in class 3 with medium clean freshwater resources.

2. Benthic macroinvertebrates were found in the upper part of Chi river basin and were classified into 8 orders/classes 25 families. The most abundant orders were Odonata and the most abundant family was Gomphidae.

3. The biological indices used for this study were diversity index, HBI index and ASPT. The diversity index was used to assess the water quality. The value of the diversity index did not agree with the water quality assessed by physicochemical parameters. It may be because of the small amount of benthic macroinvertebrates collected. Whereas, the water quality assessed by HBI index and ASPT index agreed with the water quality assessed by physicochemical parameters ($P<0.05$).

4. Benthic macroinvertebrates and physicochemical parameters were analyzed by cluster analysis. Benthic macroinvertebrates were classified into 4 groups and physicochemical parameters were also classified into 4 groups. According to PCA analysis, it indicated that the water quality and biological indices had a positive relation ($P<0.05$).

5. In regarding to the water quality in the Chi river, it indicated that the water quality and the number of aquatic organisms in the upstream were not different from the downstream. It may be because of the building barriers, and this made the water quality change especially water velocity which effects on other water quality.

6. Suggestions

6.1 The findings indicate that the water quality in some sampling sites i.e. site 7 and site 10 become polluted. It may be because of the building barriers, and this made the water quality change especially water velocity. The bio-diversity has decreased gradually because of the ecosystem change. Therefore, the water quality should be assessed regularly.

6.2 The Benthic macroinvertebrates samples from a deep and big river or reservoir should be collected by an appropriate method for a further study. And a researcher who wishes to study and identify the benthic macroinvertebrates samples should study aquatic invertebrates precisely or work with the advisors and the experts in this field.

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APPENDICES

APPENDIX A

SURFACE WATER QUALITY STANDRDS OF THAILAND

Table 1A Surface Water Quality Standards of Thailand

Parameter	Units	Statistics	Standard Value for Class					Methods for Examination
			Class 1	Class 2	Class 3	Class 4	Class 5	
1. Colour, Odour and Taste	-	-	n	n'	n'	n'	-	-
2. Temperature	°C	-	n	n'	n'	n'	-	Thermometer
3. pH	-	-	n	5-9	5-9	5-9	-	Electrometric pH Meter
4. Dissolved Oxygen (DO)[2/]	mg/L	P20	n	6.0	4.0	2.0	-	Azide Modification
5. BOD (5days, 20°C)	mg/L	P80	n	1.5	2.0	4.0	-	Azide Modification at 20°C , 5 days
6. Total Coliform Bacteria	MPN/ 100 ml	P80	n	5,000	20,000	-	-	Fermentation Technique
7. Fecal Coliform Bateria	MPN/ 100 ml	P80	n	1,000	4,000	-	-	Fermentation Technique
8. NO_3 - N	mg/L	-	n		5.0		-	Cadmium Reduction
9. NH_3 - N	mg/L	-	n		0.5		-	Distillation Nesslerization
10.Phenols	mg/L	-	n		0.005		-	Distillation,4-Amino antipyrene
11.Copper (Cu)	mg/L	-	n		0.1		-	Atomic Absorption – Direct Aspiration
12.Nickel (Ni)	mg/L	-	n		0.1		-	Atomic Absorption – Direct Aspiration
13.Manganese (Mn)	mg/L	-	n		1.0		-	Atomic Absorption – Direct Aspiration
14.Zinc (Zn)	mg/L	-	n		1.0		-	Atomic Absorption – Direct Aspiration

Table 1A (Continued)

Parameter	Units	Statistics	Standard Value for Class					Methods for Examination
			Class 1	Class 2	Class 3	Class 4	Class 5	
15.Cadmium (Cd)	mg/L	-	n		0.005* 0.05**		-	Atomic Absorption – Direct Aspiration
16.Chromium Hexavalent	mg/L	-	n		0.05		-	Atomic Absorption – Direct Aspiration
17.Lead (Pb)	mg/L	-	n		0.05		-	Atomic Absorption – Direct Aspiration
18.Total Mercury (Total Hg)	mg/L	-	n		0.002		-	Atomic Absorption – Vapour Technique
19.Arsenic (As)	mg/L	-	n		0.01		-	Atomic Absorption – Direct Aspiration
20.Cyanide (Cyanide)	mg/L	-	n		0.005		-	Pyridine – Barbituric Acid
21.Radioactivity - Alpha - Beta	Becqurel/L	-	n		0.1 1.0		-	Gas-Chromatography
22.Total Organo-chlorine Pesticides	mg/L	-	n		0.05		-	Gas-Chromatography
23.DDT	µg/L	-	n		1.0		-	Gas-Chromatography
24.Alpha-BHC	µg/L	-	n		0.02		-	Gas-Chromatography
25.Dieldrin	µg/L	-	n		0.1		-	Gas-Chromatography
27.Heptachlor & Heptachlorepoxide	µg/L	-	n		0.2		-	Gas-Chromatography
28.Endrin	µg/L	-	n		None		-	Gas-Chromatography

Remark : P = Percentile

n = naturally

n' = naturally but changing not more than 3°C

* = when water hardness not more than 100 mg/L as $CaCO_3$

** = when water hardness more than 100 mg/L as $CaCO_3$

Source: กรมควบคุมมลพิษ. (2547)

Table 2A Classification and Objectives

Classification	Objectives/Condition and Beneficial Usage
Class 1	Extra clean fresh surface water resources used for: (1) conservation not necessary pass through water treatment process require only ordinary process for pathogenic destruction (2) ecosystem conservation where basic organisms can breed naturally
Class 2	Very clean fresh surface water resources used for : (1) consumption which requires ordinary water treatment process before use (2) aquatic organism of conservation (3) fisheries (4) recreation
Class 3	Medium clean fresh surface water resources used for : (1) consumption, but passing through an ordinary treatment process before using (2) agriculture
Class 4	Fairly clean fresh surface water resources used for : (1) consumption, but requires special water treatment process before using (2) industry
Class 5	The sources which are not classification in class 1- 4 and used for navigation.

APPENDIX B

MEAN AND STANDARDS DEVIATION OF WATER QUALITY IN THE UPPER PART OF CHI RIVER BASIN FROM FEBRUARY TO DECEMBER 2004

Table 1B Mean and standard deviation of water temperature (°C) in the upper part of Chi River basin from February to December 2004

Sites / Months	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
February	23.12 ±0.84	24.28±0.70	24.42±0.58	24.55±0.30	23.37±0.88	23.50±0.34	23.60±0.36	26.83±0.27	27.07±1.74	28.35±0.37
April	28.03±0.12	31.85±0.08	31.18±0.26	31.62±0.15	30.32±0.23	35.33±0.16	34.17±0.08	34.18±0.10	33.73±0.56	32.55±0.91
June	29.40±0.66	33.38±0.97	32.38±0.89	32.82±1.13	33.03±0.55	28.58±0.15	28.50±0.15	30.43±1.29	29.23±0.28	28.52±1.30
August	28.95±0.36	27.70±0.25	28.17±0.14	29.15±0.10	30.00±0.24	31.30±0.11	31.27±0.15	35.03±1.40	31.55±0.91	30.68±0.90
October	27.25±1.17	26.77±0.96	27.67±1.19	27.82±0.42	25.10±0.18	31.93±0.84	31.13±0.52	32.18±0.31	28.32±0.42	26.63±0.08
December	27.23±1.14	28.05±1.11	28.92±2.01	26.35±0.45	24.33±0.05	23.93±0.16	23.60±0.31	23.78±0.44	22.35±0.31	21.80±0.33

Table 2B Mean and standard deviation of dissolved oxygen (mg/L) in the upper part of Chi River basin from February to December 2004

Sites / Months	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
February	7.95±0.40	8.08±0.59	7.84±0.43	6.17±0.86	4.64±0.55	8.34±0.30	5.64±0.40	5.93±0.33	7.25±0.46	7.53±0.17
April	5.77±0.89	4.91±0.31	4.46±0.37	4.69±0.17	7.17±1.45	6.19±0.46	6.32±0.18	6.26±0.26	4.37±0.33	5.74±0.45
June	4.43±0.44	4.10±0.82	5.00±0.25	5.19±0.22	5.41±0.71	3.41±0.35	4.02±0.45	4.03±0.60	4.29±0.37	5.37±0.69
August	6.15±0.35	5.75±0.48	5.49±0.17	5.47±0.18	5.68±0.17	4.07±0.62	4.40±0.52	4.57±0.30	4.93±0.48	6.47±0.18
October	6.34±0.23	6.33±0.31	5.84±0.27	6.26±0.07	5.91±0.21	5.03±0.50	5.38±0.45	4.78±0.08	3.72±0.21	4.66±0.27
December	6.13±0.21	5.10±0.18	5.54±0.33	6.15±0.30	5.27±0.19	7.46±0.09	5.37±0.32	5.51±0.11	4.69±0.10	4.08±0.18

Table 3B Mean and standard deviation of pH in the upper part of Chi River basin from February to December 2004

Sites / Months	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
February	7.25±0.25	7.83±0.05	8.15±0.48	7.87±0.05	7.17±0.08	7.28±0.15	6.95±0.18	7.07±0.47	8.33±0.10	8.88±0.25
April	6.74±0.28	7.61±0.08	7.44±0.10	7.63±0.07	7.72±0.21	7.63±0.09	7.63±0.09	7.53±0.07	7.54±0.01	8.28±0.05
June	7.35±0.16	7.01±0.33	7.08±0.10	6.88±0.09	7.01±0.08	7.28±0.11	7.46±0.06	7.28±0.09	7.36±0.05	7.24±0.02
August	6.73±0.11	7.45±0.02	7.48±0.01	7.63±0.01	7.48±0.02	7.62±0.04	7.51±0.04	7.39±0.19	7.49±0.06	7.24±0.40
October	6.21±0.07	7.27±0.06	7.30±0.17	7.30±0.03	7.33±0.02	7.57±0.07	7.33±0.06	7.25±0.05	7.03±0.09	7.12±0.01
December	6.12±0.04	7.11±0.03	7.20±0.06	7.44±0.02	7.11±0.07	7.03±0.07	7.78±0.16	6.94±0.02	6.80±0.01	6.79±0.01

Table 4B Mean and standard deviation. of turbidity (NTU) in the upper part of Chi River basin from February to December 2004

Sites / Months	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
February	0.63±0.14	1.53±0.01	3.68±0.93	3.30±1.17	3.58±0.19	1.86±0.01	3.69±0.42	8.54±0.90	3.48±0.51	2.39±0.23
April	0.40±0.03	1.63±0.23	1.06±0.14	1.65±0.20	6.50±0.67	4.61±0.72	4.61±0.72	8.76±0.84	4.62±0.45	2.23±0.36
June	8.08±0.31	16.62±2.65	53.15±2.39	57.83±4.49	45.37±3.68	69.27±6.13	60.28±2.21	107.83±0.98	142.00±9.98	175.67±42.85
August	6.79±0.57	149.67±38.98	169.83±26.75	36.65±2.64	34.18±2.88	33.53±2.30	21.28±1.75	33.13±1.02	36.07±3.36	30.12±0.71
October	0.73±0.24	0.74±0.06	4.67±3.27	3.84±1.17	4.03±0.85	3.94±0.37	4.50±0.32	16.65±3.47	9.26±0.89	2.86±0.21
December	2.44±0.47	2.31±0.23	5.29±0.59	4.01±0.91	12.45±0.77	7.72±2.64	2.00±0.24	7.25±0.72	2.37±0.63	3.53±0.27

Table 5B Mean and standard deviation. of electrical conductivity (µs/cm) in the upper part of Chi River basin from February to December 2004

Sites / Months	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
February	32.37±0.40	351.33±3.33	353.83±18.28	452.17 ±4.79	1010.00±1.79	1085.83±0.98	1007.83±0.98	756.17±2.56	972.00±68.39	697.00±7.38
April	182.00±63.19	301.33±2.34	301.17±2.56	1031.33 ±1.51	1009.33±4.63	1046.33±4.32	1046.83±4.45	965.67±24.54	1014.00±1.10	467.83±1.72
June	30.88±1.63	179.17±1.33	153.67±2.80	168.00 ±1.55	192.17±2.32	223.33±0.52	207.83±1.17	226.00±1.55	237.50±1.05	232.50±3.08
August	26.12±0.50	163.00±1.41	147.83±2.14	171.50 ±1.38	200.00±1.26	323.33±1.51	318.17±2.64	284.33±2.07	375.50±14.60	366.33±3.72
October	27.07±0.57	281.83±2.14	285.00±1.26	367.33 ±5.20	571.17±5.53	813.33±6.53	678.50±9.38	455.17±4.58	718.50±9.89	507.67±4.97
December	30.15±1.40	282.67±3.83	286.50±3.21	371.00 ±5.69	649.33±7.69	1045.00±0.89	1052.50±1.05	891.00±25.88	808.17±7.36	732.67±5.85

Table 6B Mean and standard deviation of hardness (mg/L $CaCO_3$) in the upper part of Chi River basin from February to December 2004

Sites / Months	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
February	53.35±15.15	170.41±6.50	147.54±15.14	168.56±7.72	173.22±8.06	163.35±12.66	166.64±10.13	135.02±5.25	138.31±7.92	142.27±7.50
April	156.24±7.86	174.55±11.29	160.71±21.74	167.30±13.61	164.01±12.93	164.66±10.80	172.56±19.31	166.64±4.62	158.74±11.01	104.07±8.63
June	99.46±5.82	179.12±12.40	87.61±18.12	118.56±28.82	81.01±9.60	60.60±2.04	128.44±43.71	90.24±21.27	65.86 ±9.24	41.50 ±2.16
August	50.83±3.31	89.86±7.16	97.51±7.55	89.22±3.95	85.40±6.70	87.31±5.08	91.13±10.38	76.48 ±6.40	87.31±24.71	75.20±12.49
October	58.83±2.32	154.46±12.26	168.52±9.04	165.92±5.38	195.85±11.42	135.99±76.76	134.03±12.51	87.18±11.56	93.69 ±8.19	91.09±15.32
December	54.70±3.87	179.28±7.13	180.61±8.23	173.97±4.83	205.17±6.04	202.51±6.37	243.68±9.57	146.08±10.59	152.72±27.10	128.15±16.22

Table 7B Mean and standard deviation of alkalinity (mg/L $CaCO_3$) in the upper part of Chi River basin from February to December 2004

Sites / Months	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
February	21.67±4.08	33.33±1.63	32.33±0.82	33.37±4.51	26.33±1.75	21.70±1.46	26.50±3.94	22.17±1.94	24.17±2.40	23.67±1.97
April	29.50±3.27	30.67±2.25	30.00±2.10	32.17±2.48	20.00±2.53	35.67±1.51	38.67±3.01	35.83±2.23	33.33±1.63	34.33±3.88
June	20.00±1.90	20.00±1.26	19.67±0.82	20.00±2.19	19.00±1.10	19.33±1.63	18.33±1.97	19.67±1.51	19.68±1.04	21.00±1.10
August	19.00±1.26	19.67±0.82	18.33±1.51	18.00±1.26	18.00±1.26	17.67±1.51	17.67±1.51	16.00±1.26	14.67±1.03	17.33±1.21
October	32.33±1.51	34.33±1.51	25.67±1.51	32.67±1.63	33.33±2.07	22.67±1.63	19.33±1.03	20.00±1.79	21.00±1.67	20.00±1.79
December	29.21±10.29	37.33±1.63	36.33±2.34	33.33±8.16	37.00±1.67	30.33±3.20	32.00±1.26	25.00±2.76	24.00±2.83	22.67±1.63

Table 8B Mean and standard deviation of biochemical oxygen demand (mg/L) in the upper part of Chi River basin from February to December 2004

Sites / Months	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
February	1.40±0.70	1.48±0.56	2.20±0.45	1.97±0.87	1.63±0.31	1.28±0.23	1.40±1.43	1.28±0.19	2.20±0.74	1.23±0.43
April	2.07±0.41	2.12±0.26	3.05±0.99	2.13±0.53	2.53±0.61	1.60±0.24	1.53±0.26	3.53±0.46	3.32±0.68	4.60±0.62
June	1.30±0.89	1.42±0.42	1.58±0.57	2.66±2.33	1.25±0.84	3.78±0.42	3.83±0.62	3.97±3.87	1.15±0.29	2.55±0.31
August	1.20±0.67	2.80±2.31	1.90±0.88	0.95±0.64	1.77±1.15	2.92±0.59	1.77±0.66	1.32±0.59	3.53±2.20	1.72±0.42
October	1.13±0.37	0.38±0.19	0.48±0.29	0.45±0.12	0.82±0.44	1.80±0.37	1.87±0.54	1.88±0.26	1.92±0.42	4.73±0.40
December	1.73±0.55	2.83±0.30	1.75±0.31	2.60±0.41	1.40±0.30	4.87±0.40	1.98±0.33	1.52±0.71	4.23±0.49	5.48±0.80

Table 9B Mean and standard deviation of phosphate (mg/L) in the upper part of Chi River basin from February to December 2004

Sites / Months	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
February	0.01±0.01	0.01±0.01	0.01±0.01	0.01±0.00	0.01±0.00	0.01±0.00	0.01±0.00	0.02±0.00	0.01±0.00	0.01±0.00
April	0.01±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.02±0.01	0.01±0.01	0.01±0.00	0.01±0.01	0.01±0.01	0.01±0.00
June	0.02±0.01	0.01±0.01	0.02±0.00	0.02±0.00	0.03±0.01	0.06±0.00	0.05±0.01	0.05±0.01	0.09±0.04	0.07±0.01
August	0.05±0.00	0.09±0.01	0.07±0.01	0.02±0.00	0.02±0.00	0.03±0.01	0.03±0.01	0.03±0.01	0.03±0.00	0.03±0.01
October	0.02±0.01	0.01±0.00	0.00±0.01	0.02±0.01	0.03±0.03	0.01±0.00	0.00±0.00	0.02±0.00	0.01±0.01	0.01±0.00
December	0.00±0.00	0.01±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.01±0.00	0.00±0.00	0.01±0.00

Table 10B Mean and standard deviation of nitrate (mg/L) in the upper part of Chi River basin from February to December 2004

Sites / Months	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
February	0.00±0.00	0.23±0.37	0.19±0.01	0.15±0.05	0.08±0.05	0.25 ±0.02	0.11±0.04	0.13±0.11	0.23±0.10	0.21±0.01
April	0.22±0.02	0.13±0.02	0.20±0.00	0.12±0.01	0.24±0.03	0.14 ±0.02	0.15±0.04	0.07±0.07	0.17±0.10	0.13±0.04
June	0.21±0.01	0.23±0.04	0.25±0.07	0.28±0.04	0.22±0.06	0.09 ±0.05	0.17±0.04	0.14±0.07	0.21±0.03	0.18±0.08
August	0.24±0.02	0.23±0.02	0.20±0.02	0.17±0.02	0.19±0.02	0.21±0.03	0.22±0.01	0.29±0.03	0.21±0.02	0.23±0.03
October	0.14±0.06	0.12±0.01	0.13±0.00	0.19±0.03	0.22 ±0.01	0.10±0.10	0.13±0.11	0.14±0.03	0.18±0.03	0.20±0.03
December	0.38±0.08	0.11±0.02	0.02±0.01	0.11±0.04	0.11 ±0.04	0.13±0.02	0.03±0.07	0.17±0.02	0.14±0.01	0.12±0.03

Table 11B Mean and standard deviation of ammonia (mg/L) in the upper part of Chi River basin from February to December 2004

Sites / Months	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
February	0.03±0.01	0.02±0.00	0.03±0.02	0.04±0.03	0.03±0.02	0.05±0.02	0.08±0.04	0.15±0.07	0.05±0.03	0.03±0.00
April	0.04±0.01	0.07±0.01	0.07±0.00	0.10±0.02	0.07±0.01	0.07±0.01	0.03±0.01	0.07±0.00	0.06± 0.01	0.06±0.01
June	0.05±0.02	0.06±0.02	0.03±0.01	0.04±0.01	0.05±0.01	0.04±0.00	0.03±0.00	0.03±0.00	0.36±0.01	0.23±0.01
August	0.28±0.01	0.12±0.01	0.35±0.02	0.19±0.01	0.21±0.01	0.23±0.00	0.23±0.01	0.22±0.02	0.23±0.00	0.20±0.00
October	0.32±0.04	0.32±0.03	0.32±0.03	0.33±0.04	0.32±0.02	0.28±0.01	0.23±0.03	0.30±0.02	0.34±0.03	0.03±0.01
December	0.24±0.02	0.03±0.00	0.26±0.02	0.24±0.02	0.28±0.02	0.27±0.03	0.25±0.04	0.23±0.01	0.27±0.06	0.33±0.07

Table 12B Mean and standard deviation of water velocity (m /s) in the upper part of Chi River basin from February to December 2004

Sites / Months	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
February	0.10±0.00	0.90±0.00	0.05±0.00	0.10±0.00	0.10±0.00	0.03±0.00	0.04±0.00	0.03±0.00	0.03±0.00	0.03±0.00
April	0.10±0.00	0.20±0.00	0.10±0.00	0.04±0.00	0.06±0.00	0.03± 0.00	0.05±0.00	0.04±0.00	0.05±0.00	0.04±0.00
June	0.18±0.00	0.29±0.00	0.11±0.00	0.30±0.00	0.25±0.00	0.19±0.00	0.18±0.00	2.26±0.00	0.42±0.00	0.04±0.00
August	2.33±0.00	3.02±0.00	0.22±0.00	0.36±0.00	2.43±0.00	0.12±0.00	0.12±0.00	0.15±0.00	0.37±0.00	0.18±0.00
October	0.29±0.00	0.34±0.00	0.27±0.00	0.23±0.00	0.11±0.00	0.03±0.00	0.04±0.00	0.03±0.00	0.03±0.00	0.04±0.00
December	0.19±0.00	0.17±0.00	0.10±0.00	0.05±0.00	0.04±0.00	0.05±0.00	0.04±0.00	0.05±0.00	0.05±0.00	0.04±0.00

APPENDIX C

HBI TOLERANCE VALUES

Table 1C olerance Values for macroinvertebrates application the Modified Family Biotic Index and other metrics (Bode et al., 1996: Hauer & Lamberti, 1996: Hilsenhoff, 1988: Plafkin et al., 1989)

Taxon	Tolerance
Class Collembola	
Isotomurus sp.	5
Order Ephemeroptera	
Baetidae	4
Baetiscidae	3
Caenidae	7
Ephemerellidae	1
Ephemridae	4
Heptageniidae	4
Leptophlebiidae	2
Metretopodidae	2
Oligoneuriidae	2
Polymitarcyidae	2
Potomanthidae	4
Siphlonuridae	7
Tricorythidae	4
Order Plecoptera	
Capniidae	1
Chloroperlidae	1
Leuctridae	0
Nemouridae	2
Perlidae	1
Perlodidae	2
Pteronarcyidae	0
Taeniopterygidae	2
Order Lepidoptera	
Pyralidae	5
Order Coleoptera	
Dryopidae	5
Elmidae	4

Table 1C (Continue)

Taxon	Tolerance
Order Odonata	
Aeshnidae	3
Calopterygidae	5
Coenagrionidae	9
Cordulegastridae	3
Corduliidae	5
Gomphidae	1
Lestidae	9
Libellulidae	9
Macromiidae	3
Order Trichoptera	
Brachycentridae	1
Calamoceratidae	3
Glossosomatidae	0
Helicopsychidae	3
Hydropsychidae	4
Hydroptilidae	4
Lepidostomatidae	1
Letoceridae	4
Limnephilidae	4
Molannidae	6
Odontoceridae	0
Philpotamidae	3
Phryganeidae	4
Polycentropodidae	6
Psychomyiidae	2
Psephenidae	4
Order Megaloptera	
Corydalidae	0
Sialidae	4
Order Diptera	
Athericdae	2
Blephariceridae	0
Ceratopogonidae	6
Biood - red Chironomidae (Chironomini)	8

Table 1C (Continue)

Taxon	Tolerance
Other Chironomidae (including pink)	6
Dolochopodidae	4
Empididae	6
Ephydridae	6
Muscidae	6
Psychodidae	10
Simuliidae	6
Syrphidae	10
Tabanidae	6
Tipulidae	3
Phylum Mollusca	
Lymnaeidae	6
Physidae	8
Sphaeridae	8
Class Oligochaeta	8
Class Turbellaria	4
Platyhelminthidae	4
Rhyacophilidae	0
Sericostomatidae	3
Uenoidae	3
Order Neuroptera	
Sisyridae	
Climacia sp.	5
Order Amphipoda	
Gammaridae	4
Hyalellidae	8
Talitridae	8
Order Isopoda	
Asellidae	8
Order Decapoda	6
Order Acariformes	4

Table 1C (Continue)

Taxon	Tolerance
Phylum Coelenterata	
Hydridae	
Hydra sp.	5
Class Hirudinea	
Bdellidae	10
Helobdella	10
Class Polychaeta	6

Table 2C Interpretation of HBI Scores

Biotic Index	Water Quality	Degree of Organic Pollution
0.00 - 3.50	Excellent	No apparent organic pollution
3.51 - 4.50	Very good	Possible slight organic pollution
4.51 - 5.50	Good	Some organic pollution
5.51 - 6.50	Fair	Fairly significant organic pollution
6.51 - 7.50	Fairly poor	Significant organic pollution
7.51 - 8.50	Poor	Very significant organic pollution
8.51 - 10.00	Very poor	Severe organic pollution

Source: Bode et al., 1996: Hauer & Lamberti, 1996: Hilsenhoff, 1988: Plafkin et al., 1989

APPENDIX D

BMWP^{Thai} SCORE VALUES

Table 1D The BMWP score system modified by Mustow 2002

Order/Class	Family	BMWP score
O.Ephemeroptera	Baetidae, Siphonuliidae	4
	Caenidae	7
	Ephemerellidae, Ephemeridae, Hepageniidae, Leptophlebiidae, Potamanthidae	10
O.Donata	Aeshnidae, Calopterygidae, Corduliidae, Coenagrioniidae, Macromiidae, Platystidae, Libellulidae, Gomphidae, Cordulegastridae	6
	Protoneuridae	3
O.Plecoptera	Nemouridae	7
	Perlidae	10
O.Hemiptera	Aphelocheiridae	10
	Corixidae, Gerridae, Hydrometridae, Pleidae, Mesoveliidae, Naucoridae, Nepidae, Notonectidae	5
O.Trichoptera	Goeridae, Lepidostomatidae, Leptoceridae, Molannidae, Odontoceridae,	10
	Polycentropodidae, Stenopsychidae, Rhyacophilidae	7
	Hydroptilidae	6
	Hydropsychidae	5
O.Coleoptera	Chrysomelidae, Cureulionidae, Dryopidae, Dytiscidae, Elminthidae, Gyrinidae, Haliplidae, Helodidae, Hydrophilidae, Psephenidae	5
O.Diptera	Chironomidae	2
	Simuliidae, Tipulidae	5
Cl.Tricladida	Dugesiidae	5
Cl.Oligochaeta	All	1
Cl.Hirudinea	Erpobdellidae, Glossiphoniidae, Hirudidae	3
	Piscicolidae	4
Cl.Bivalvia	Curbiculidae, Shaeriida	3
Cl.Gastropoda	Hydrobiidae, Triaridae, Lymnaeidae, Planorbidae	3
	Viviparidae, Ancylidae	6
O.Decapoda	Atyidae, Palaemonidae	8
	Parathelphusidae	3
O.Megaloptera	Corydalidae, Sialidae	4

Table 2D Interpretation of ASPT

ASPT	Water Quality Standard	Water Quality Assessment
1 - 2	Class5	Very poor
3 - 4	Class4	Fairy poor
5 - 6	Class3	Moderate
7 - 8	Class2	Fairy good
9 - 10	Class1	Good

Source: Mustow, 2002.

APPENDIX E

BIOLOGICAL INDICE VALUES

Table 1E Biological Indice Values

Site	Months	Biological Indices		
		Diversity	HBI	ASPT
C_1	February	1.43	4.64	5.00
	April	0.97	2.33	5.60
	June	0.90	4.87	5.40
	August	1.91	2.90	5.80
	October	0.68	3.75	6.00
	December	1.15	2.48	5.90
C_2	February	1.52	4.35	6.00
	April	1.03	3.25	5.90
	June	1.08	3.47	5.80
	August	-	-	-
	October	0.80	4.02	6.00
	December	0.80	2.80	6.00
C_3	February	1.16	4.80	7.30
	April	1.24	5.00	5.50
	June	0.79	5.56	3.90
	August	1.22	4.60	5.50
	October	0.96	3.15	6.00
	December	0.21	3.23	6.00
C_4	February	1.46	6.67	4.90
	April	1.18	5.08	6.00
	June	0.92	6.67	5.30
	August	-	-	-
	October	0.32	4.02	6.00
	December	1.87	4.78	5.60
C_5	February	1.62	4.21	5.70
	April	1.23	3.81	5.90
	June	1.12	6.85	5.80
	August	0.95	5.56	5.40
	October	0.37	3.15	6.00
	December	1.23	4.71	5.50
C6	February	1.03	6.89	5.40
	April	1.21	6.75	6.00
	June	0.47	6.67	5.00
	August	1.47	6.33	4.60
	October	1.03	4.23	5.60
	December	0.90	3.70	5.90

Table 1E (Continued)

Site	Months	Biological Indices		
		Diversity	HBI	ASPT
C_7	February	1.46	5.18	5.60
	April	0.96	6.00	4.70
	June	0.50	3.00	5.10
	August	1.01	8.00	5.50
	October	1.09	3.20	5.80
	December	1.71	4.16	5.90
C_8	February	1.28	5.80	5.50
	April	1.04	5.00	6.40
	June	0.43	8.00	5.10
	August	-	-	-
	October	1.17	5.00	5.70
	December	0.64	4.16	5.80
C_9	February	1.08	5.92	5.60
	April	0.76	8.00	5.60
	June	0.94	6.00	5.50
	August	1.13	6.00	5.60
	October	1.39	4.90	5.90
	December	1.39	4.90	5.90
C_{10}	February	0.59	7.87	5.90
	April	1.41	6.67	5.60
	June	0.90	8.00	5.40
	August	1.16	6.75	5.50
	October	1.6	4.64	5.50
	December	1.35	7.53	5.80

Remark: No data (-) because it was in the flood season.

Table 2E Interpretation of Biological Indice Values

Site	Months	Biological Indices		
		Diversity	HBI	ASPT
C_1	February	Moderate pollution	Good	Moderate
	April	Polluted	Excellent	Moderate
	June	Polluted	Good	Moderate
	August	Moderate pollution	Excellent	Moderate
	October	Polluted	Very good	Moderate
	December	Moderate	Excellent	Moderate
C_2	February	Moderate pollution	Very good	Moderate
	April	Moderate	Excellent	Moderate
	June	Moderate	Excellent	Moderate
	August	-	-	-
	October	Polluted	Very good	Moderate
	December	Polluted	Excellent	Moderate
C_3	February	Moderate pollution	Good	Fairly good
	April	Moderate pollution	Good	Moderate
	June	Polluted	Fair	Fairly poor
	August	Moderate pollution	Good	Moderate
	October	Polluted	Excellent	Moderate
	December	Polluted	Excellent	Moderate
C_4	February	Moderate pollution	Fairly poor	Fairly good
	April	Moderate pollution	Good	Moderate
	June	Polluted	Fairly good	Moderate
	August	-	-	-
	October	Polluted	Very good	Moderate
	December	Moderate pollution	Good	Moderate
C5	February	Moderate pollution	Fairly poor	Moderate
	April	Moderate pollution	Good	Moderate
	June	Polluted	Fairly poor	Moderate
	August	-	-	-
	October	Polluted	Very good	Moderate
	December	Moderate pollution	Good	Moderate

Table 2E (Continued)

Site	Months	Biological Indices		
		Diversity	HBI	ASPT
C_6	February	Moderate pollution	Fairly poor	Moderate
	April	Moderate pollution	Fairly poor	Moderate
	June	Polluted	Fairly poor	Moderate
	August	Moderate pollution	Fair	Fairly poor
	October	Moderate pollution	Very good	Moderate
	December	Polluted	Very good	Moderate
C_7	February	Moderate pollution	Good	Moderate
	April	Polluted	Fair	Fairly poor
	June	Polluted	Excellent	Moderate
	August	Moderate pollution	Fairly poor	Moderate
	October	Moderate pollution	Excellent	Moderate
	December	Moderate pollution	Very good	Moderate
C_8	February	Moderate pollution	Fair	Moderate
	April	Moderate pollution	Very good	Moderate
	June	Polluted	Poor	Moderate
	August	-	-	-
	October	Moderate pollution	Fair	Moderate
	December	Polluted	Very good	Moderate
C_9	February	Moderate pollution	Fair	Moderate
	April	Polluted	Poor	Moderate
	June	Polluted	Fair	Moderate
	August	Moderate pollution	Fair	Moderate
	October	Moderate pollution	Good	Moderate
	December	Moderate pollution	Good	Moderate
C_{10}	February	Polluted	Poor	Moderate
	April	Moderate pollution	Fairly poor	Moderate
	June	Polluted	Poor	Moderate
	August	Moderate pollution	Fairly poor	Moderate
	October	Moderate pollution	Good	Moderate
	December	Moderate pollution	Poor	Moderate

Table 3E Diversity value

< 1.5	1.5 - 3	> 3.5
polluted	Moderate	Good

Source: FAO (2006).

APPENDIX F

BENTHIC MACROINVERTEBRATE SAMPLES FROM THE UPPER PART OF CHI RIVER BASIN FROM FEBRUARY TO DECEMBER 2004

Table 1F Benthic macroinvertebrates in February 2004

Order / Class	Family	Count
Hemiptera	Nepidae	86
	Naucoridae	7
	Notonectidae	7
Ordonata	Macromiidae	12
	Gomphidae	37
	Chlorocyphidae	3
	Coenagrionidae	96
	Libellulidae	1
	Corduliidae	34
	Protoneuridae	5
	Petaluridae	7
	Aeshnidae	3
Decapoda	Mysidae	5
Veneroida	Corbiculidae	1
Gastropoda	Bithyniidae	4
	Pleuroceridae	2
Isopoda	Corallanidae	7
	Cirolanidae	1
Trichoptera	Leptoceridae	1
Total 7	19	319

Table 2F Benthic macroinvertebrates in April 2004

Order / Class	Family	Count
Hemiptera	Nepidae	55
	Naucoridae	2
	Notonectidae	8
Ordonata	Macromiidae	18
	Gomphidae	13
	Chlorocyphidae	5
	Coenagrionidae	85
	Corduliidae	51
Veneroida	Corbiculidae	1
Total 4	10	238

Table 3F Benthic macroinvertebrates in June 2004

Order / Class	Family	Count
Hemiptera	Nepidae	133
	Naucoridae	3
	Notonectidae	1
Ordonata	Macromiidae	19
	Gomphidae	24
	Coenagrionidae	34
	Corduliidae	2
Decapoda	Mysidae	3
Isopoda	Cirolanidae	1
Total 4	9	220

Table 4F Benthic macroinvertebrates in August 2004

Order / Class	Family	Count
Hemiptera	Nepidae	41
	Notonectidae	3
	Hydrometridae	1
Ordonata	Macromiidae	12
	Gomphidae	39
	Lestidae	1
	Libellulidae	3
	Cordulegastidae	1
	Corduliidae	6
	Chlorocyphidae	5
	Coenagrionidae	5
Decapoda	Mysidae	7
Gastropoda	Pleuroceridae	1
	Bithyniidae	1
Veneroida	Corbiculidae	2
Total 6	16	128

Table 5F Benthic macroinvertebrates in October 2004

Order / Class	Family	Count
Hemiptera	Nepidae	47
	Notonectidae	1
Ordonata	Gomphidae	164
	Corduliidae	24
	Coenagrionidae	9
	Aeshnidae	5
	Petaluridae	2
	Chlorocyphidae	12
Decapoda	Mysidae	33
Isopoda	Corallanidae	3
	Cirolanidae	7
Gastropoda	Pleuroceridae	2
Total 5	12	309

Table 6F Benthic macroinvertebrates in December 2004

Order / Class	Family	Count
Hemiptera	Nepidae	75
	Naucoridae	4
Ordonata	Macromiidae	12
	Gomphidae	324
	Corduliidae	45
	Coenagrionidae	71
	Chlorocyphidae	34
	Libellulidae	23
	Aeshnidae	5
	Lestidae	7
Isopoda	Corallanidae	19
	Cirolanidae	1
Ephemeroptera	Heptageniidae	2
	Baetidae	4
Total 4	14	626

APPENDIX G

STATISTICAL VALUES OF INDIVIDUAL FACTOR AND FACTOR LOADING

Table 1G Statistical values of factors

Component	Initial Eigenvalues		
	Total	**% of Variance**	**Cumulative %**
1	4.301	28.674	28.674
2	1.811	12.071	40.745
3	1.666	11.104	51.849
4	1.264	8.425	60.274
5	1.093	7.289	67.563
6	1.016	6.775	74.337
7	0.785	5.233	79.571
8	0.726	4.843	84.413
9	0.581	3.874	88.288
10	0.455	3.036	91.324
11	0.428	2.855	94.178
12	0.355	2.369	96.548
13	0.286	1.908	98.456
14	0.139	0.929	99.384
15	0.092	0.616	100.000

Table 2G Factor loading

	Component	
	1	**2**
TEMP	-0.128	0.211
DO	0.076	-0.059
PH	-0.026	0.319
TUR	-0.204	0.071
EC	0.120	0.201
HAR	0.165	0.117
ALK	0.159	0.060
BOD	-0.025	0.241
PO	-0.202	0.002
NO	-0.117	-0.076
NK	0.023	-0.354
VE	-0.114	-0.156
DIVER	0.148	-0.153
HPI	-0.004	0.218
ASPT	0.163	-0.053

Table 3G Statistical values of factors

Component	Initial Eigenvalues		
	Total	**% of Variance**	**Cumulative %**
1	4.275	21.373	21.373
2	2.212	11.062	32.435
3	1.797	8.985	41.420
4	1.470	7.350	48.770
5	1.420	7.098	55.869
6	1.235	6.177	62.046
7	1.102	5.508	67.554
8	1.067	5.337	72.891
9	0.914	4.572	77.463
10	0.807	4.036	81.499
11	0.705	3.526	85.025
12	0.627	3.137	88.161
13	0.512	2.560	90.722
14	0.479	2.393	93.115
15	0.429	2.147	95.262
16	0.315	1.573	96.835
17	0.208	1.042	97.877
18	0.182	0.910	98.786
19	0.149	0.745	99.531
20	0.094	0.469	100.000

Table 4G Factor loading

	Component	
	1	**2**
TEMP	0.112	-0.107
DO	-0.086	0.085
PH	-0.003	-0.194
TUR	0.190	-0.017
EC	-0.127	-0.158
HAR	-0.188	-0.091
ALK	-0.181	-0.028
BOD	0.003	-0.122
PO	0.191	0.053
NO	0.127	0.070
NK	0.011	0.310
VE	0.108	0.178
ODN	-0.154	0.083
HIM	0.043	-0.069
DEC	-0.012	0.014
TRI	0.009	0.288
ISO	-0.083	0.037
GAS	0.045	-0.165
EPH	-0.055	0.043
VEN	0.057	-0.171

APPENDIX H

BENTHIC MACROINVERTABRATES IN THE UPPER PART OF CHI RIVER BASIN FEBRUARY TO DECEMBER 2004

ORDER ODONATA

a

b

c

d

e

f

g

h

i

Figure 1H xamples of benthic macroinvertibrates in each family in the upper part of Chi river basin

a. Macromiidae	b. Gomphidae	c. Corduliidae
d. Chlorocyphidae	e. Gomphidae	f. Gomphidae
g. Cordulegastridae	h. Ashnidae	i. Lestidae

ORDER ODONATA (Continued)

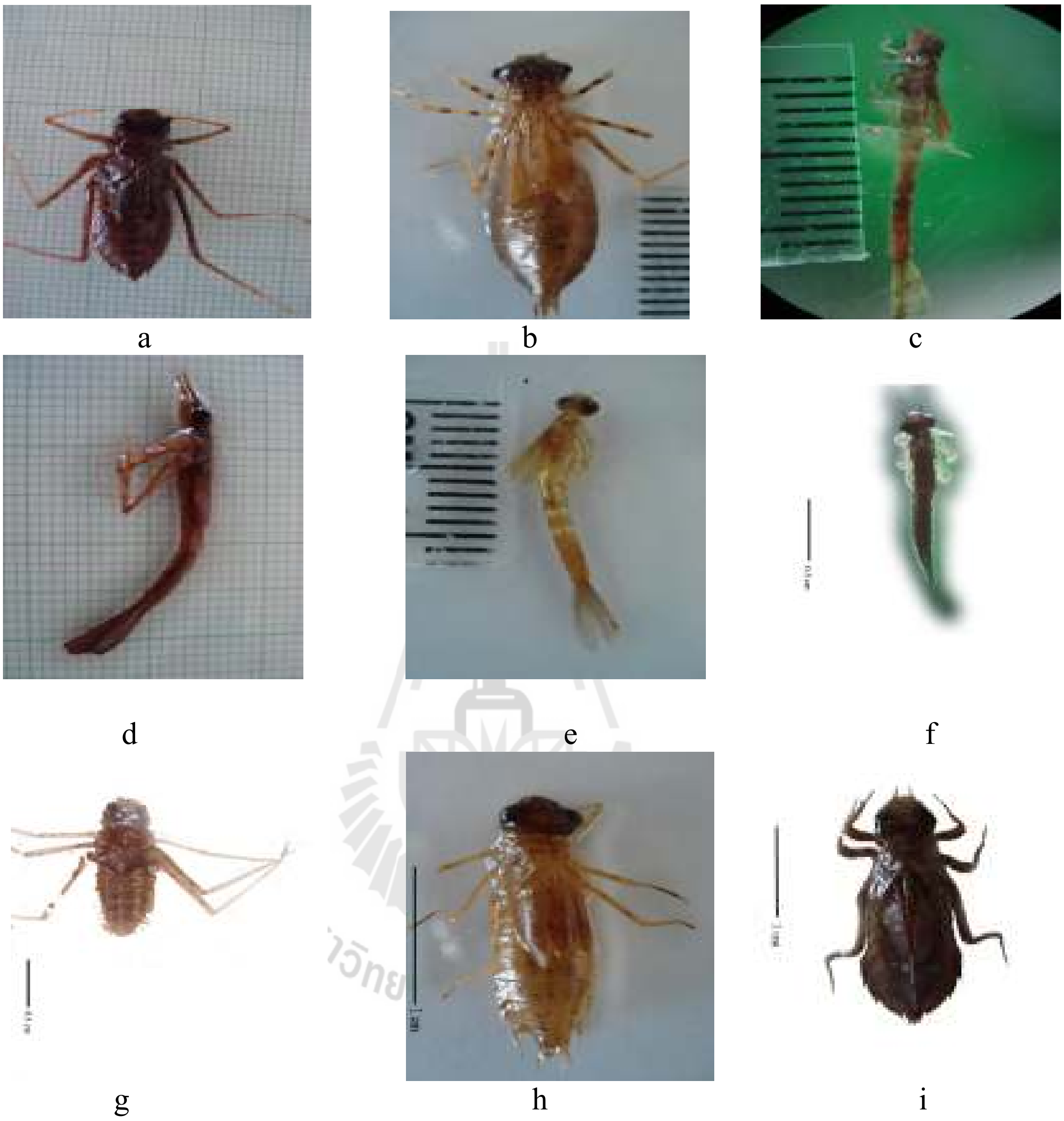


Figure 2H Examples of benthic macroinvertibrates in each family in the upper part of Chi river basin

a. Macromiidae	b. Petaluridae	c. Protoneuridae
d. Coenagrionidae	e. Coenagrionidae	f. Chlorocyphidae
g. Macromiidae	h. Libellulidae	i. Gomphidae

ORDER HEMIPTERA

a

b

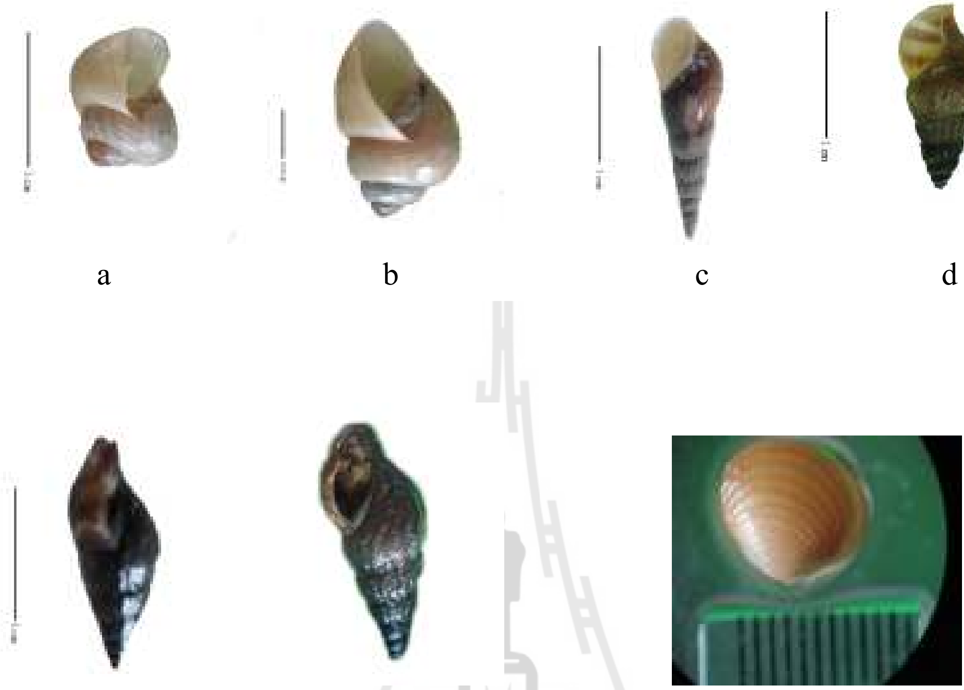
c

d

Figure 3H Examples of benthic macroinvertibrates in each family in the upper part of Chi river basin

a. Naucoridae b. Notonectidae c. Nepidae d. Nepidae

CLASS GASTROPODA and CLASS VENEROIDA



a b c d

e f g

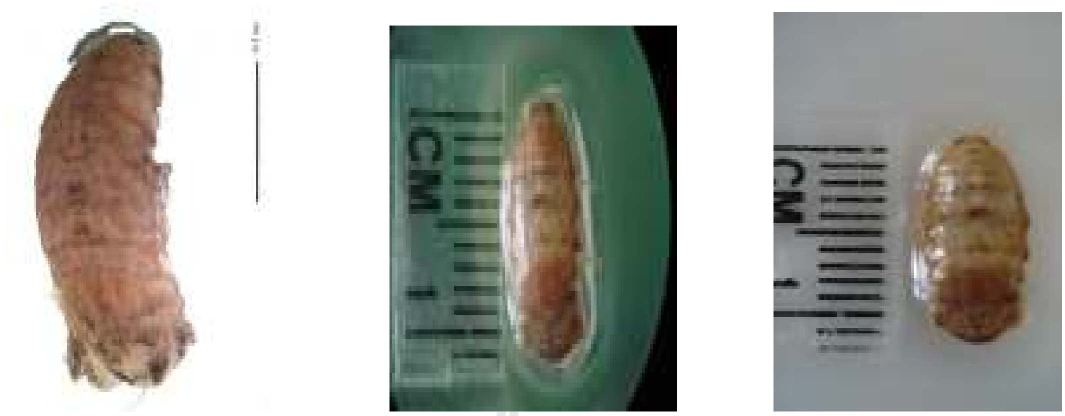
Figure 4H Examples of benthic macroinvertibrates in each family in the upper part of Chi river basin

a. Bithyniidae b. Bithyniidae c. Pleuroceridae

d. Pleuroceridae e. Pleuroceridae f. Pleuroceridae

g. Class Veneroida, (F. Corbiculidae)

ORDER ISOPODA



a b c

d e f

Figure 5H Examples of benthic macroinvertibrates in each family in the upper part of Chi river basin

a. Corallanidae b. Cirolanidae c. Cirolanidae

d. Corallanidae e. Cirolanidae f. Corallanidae

ORDER EPHEMEROPTER and ORDER TRICHOPTERA

a

b

c

d

Figure 6H Examples of benthic macroinvertibrates in each family in the upper part of Chi river basin

a. Baetidae b. Ephemeridae c. Heptageniidae

d. Order Trichoptera (F. Leptoceridae)

ORDER DECAPODA

a

b

c

Figure 7H Examples of benthic macroinvertibrates in each family in the upper part of Chi river basin

a. Mysidacea b. Mysidacea c. Mysidacea

CURRICULUM VITAE

Mr. Nukool Kudthalang was born in April 19, 1959, in Kalasin Province, Thailand. He studied the undergraduate program in Education (Chemistry) at Sri Nakharinwirot University Maha Sarakham, Thailand, and graduated in 1982. He continued the Master degree in Environmental Science at Kasetsart University, Thailand, and graduated in 1988. He studied the Ph.D. program in Environmental biology at Suranaree University of Technology in 2003. He had stared working at Kamalasia School in 1982, until 1997. He has taught for program Environmental Science at Rajabhat Maha Sarakham University Thailand since 1997.