Integrating Land Use Planning and Surface Water Quality for River Basin Management: a Case Study of U-tapao River Basin, Thailand

Saroj Gyawali

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy in Environmental Management
Prince of Songkla University
2013

Thesis Title Integrating Land Use Planning and Surface Water Quality for River Basin Management: a Case Study of U-tapao River Basin, Thailand

Author Mr. Saroj Gyawali

Major Program Environmental Management

Major Advisor :

…………………………………………..
(Dr. Kuaanan Techato)

Co-advisors :

…………………………………………..
(Dr. Sathaporn Monprapussorn)

…………………………….……………
(Asst. Prof. Dr. Charongpun Musikavong)

Examining Committee :

...……….....………………..Chairperson
(Assoc. Prof. Dr. Chatchai Ratanachai)

…………………….……………………
(Dr. Kuaanan Techato)

…………………….…………………....
(Dr. Sathaporn Monprapussorn)

…………………………………………..
(Asst. Prof. Dr. Sunya Sarapirome)

………………………………………......
(Assoc. Prof. Dr. Wannasilpa Peerapun)

The Graduate School, Prince of Songkla University, has approved this thesis as partial fulfillment of the requirements for the Doctor of Philosophy Degree in Environmental Management.

…………………………………………
(Assoc. Prof. Dr. Teerapol Srichana)
Dean of Graduate School

This is to certify that the work here submitted is the result of the candidate's own investigations. Due acknowledgement has been made of any assistance received.

______________________________Signature

(Dr. Kuaanan Techato)

Major Advisor

______________________________Signature

(Saroj Gyawali)

Candidate

I hereby certify that this work has not already been accepted in substance for any degree, and is not being concurrently submitted in candidature for any degree.

______________________________Signature

(Saroj Gyawali)

Candidate

Thesis Title	Integrating Land Use Planning and Surface Water Quality for River Basin Management: a Case Study of U-tapao River Basin, Thailand
Author	Mr. Saroj Gyawali
Major Program	Environmental Management
Academic Year	2009

ABSTRACT

Increasing population, developmental pressures, high demand of limited land resources, competition on water resources, and lack of land use planning continually contribute to the degradation of water quality of river. To curb this problem, integrating land use planning and surface water quality might be a right approach to improve water quality for environmental protection. U-tapao River Basin (URB) is a sub catchment of the Songkhla Lake Basin (SLB) which is located in the southern part of Thailand. It is an important river of the basin and very much influenced from point sources and non-point sources of pollution generated from two major cities, Hatyai and Songkhla. The main goal of this study was to formulate the effective methodology to evaluate land use planning on water quality framework in the basin level. The objectives of this study were: i) to find the relationship of land uses and water quality; ii) to prepare land use planning map on the basis of land suitability ; and iii) to evaluate land use planning on water quality framework.

Water quality data were collected from the existing monitoring framework of Regional Environmental Office-16, Songkhla and land use data were manipulated from the land use maps, provided by the Land Development Department, Thailand by using Geographic Information Systems (GIS). Correlation and regression analyses were performed to determine relationships among the water quality parameters and land uses. Analysis of variance (ANOVA) was used to determine variation of mean values of water quality parameters and land uses.

Analyzing temporal and spatial variations of water quality parameters, it was found that the water quality status of river is moderately polluted and the downstream region is more polluted than upstream region of the basin. The study also identified clear relationship between land uses and water quality parameters. The urban land showed positive correlation with water quality parameters. In contrast, the agriculture land showed negative correlation with temperature (TEMP) and biological oxygen demand (BOD) and positive correlation with dissolved oxygen (DO). Analyzing the spatial, annual and seasonal variations of water quality parameters, it was found that TEMP was the most sensitive parameter for variation analysis. By performing multiple regression analysis, four predictive models for water quality parameters (TEMP, pH, DO and BOD) in basin level were successfully established.

From land use perspective, agriculture, especially rubber is the dominating land use of the basin. Due to various reasons agriculture land has been converted to urban land thus creating serious environmental problem in the basin. The conversion of fertile agriculture land to urban land is a serious issue of policy makers or decision makers of this region. To effectively manage the land resources of the basin, the study successfully generated the land use suitability maps of agriculture (rubber), forest and urban in basin level by utilizing the concept of Multi Criteria Decision Making (MCDM) in Geographic Information Systems (GIS) environment.

By utilizing concept of land suitability analysis, this study proposed sustainable principle based land use planning map of the basin. To evaluate the effectiveness of the proposed land use planning map on water quality framework, it was compared with real land use map of the year 2009 and some other land use maps of the basin. It was found that the proposed land use planning map is better than other maps with respect to water quality.

Since the main goal of this study was to develop effective methodology to evaluate the land use planning; the study forwarded the methodology of evaluating land use planning on water quality framework. This concept is simple as well as practical and it is highly recommended to policy or decision makers of river basin and Lake Basin management to implement in real life. With slight modification of original concept, the local as well as regional planners can use this concept to evaluate their regular land use planning proposals. Besides these, the concept of this study is very useful for those academic researchers who are interested to link land use with water quality parameters and land use planning.

Keywords: Geographic Information Systems (GIS), Land use planning, Multi Criteria Decision Making (MCDM), Suitability analysis, Sustainable Development, U-tapao River Basin, Water Quality

ACKNOWLEDGEMENTS

This thesis would not have been completed without help and cooperation of many individuals and organizations. I would like to take this opportunity to thank all of them from the bottom of my heart. First, I offer my sincere gratitude to my advisor Dr. Kuaanan Techato, who guided me throughout my research and allowed me the room to work independently. I thank him for his intensive discussion on the subject matter, and timely and constructive comments. I would also like to express my deepest gratitude to my co-advisor Dr. Sathaporn Monprapussorn for his critical guidance, especially regarding land use planning and GIS sector; which was the backbone of this thesis. I would also like to express my gratitude to my next co-advisor Dr. Charongpun Musikavong for his critical comments on water quality issues. I would also like to express my sincere thanks to Dr. Chumpol Yuangyai for his guidance, critical comments, and excellent suggestions throughout this research work. I really appreciate his vast knowledge and skills in many areas. I would also like to express gratitude to Dr. Teerawet Titseesang for his critical comments and suggestions about sustainable development issues.

I would like to thank the Dean of the faculty of Environmental Management, Asst. Prof. Dr. Rotchanatch Darsnsawadi for sharing his vast knowledge on environmental modeling and for helping on land use planning. I am indebted to Asst. Prof. Dr. Thunwadee Tachapattaworakal and Assoc. Prof. Dr. Panalee Chevakidagarn for sharing their knowledge on water quality. I am also indebted to Dr. Oramas Suthinun for advising to me to make thesis format in proper

order. I would also like to express my sincere gratitude to Asst. Prof. Dr. Parichat Visuthismajarn for her support in the beginning phase of my thesis work.

I also wish to thank the staff members of GEO–Informatics Research Center for Natural Resources and Environment, especially Adul Bennui, for providing GIS data. I would also like to thank Napadol Sudsom for his help on GIS analysis. I want thank the staff members of Regional Environmental Office-16, Songkhla for providing data of water quality. I would like to thank the staff members of Land Development Department, Songkhla for their valuable information and support.

I am very much thankful to all my family members who always supported me to pursue my goal. My sincere gratitude goes to my parents for their support. My son Bikesh deserves special thanks and love for being so cute, patient and supportive when I was away from him during my study periods. Finally, very special thanks to my beloved wife Bimala for her support and understanding. Lastly, but not the least, I would like to thank everyone with whom I have interacted during my thesis work.

Saroj Gyawali

LIST OF ABBREVIATIONS

AHP	Analytic Hierarchical Process
ANOVA	Analysis of Variance
BOD	Biological oxygen demand
DEM	Digital Elevation Model
DO	Dissolved oxygen
FAO	Food and Agriculture Organization of the United Nations
FCB	Fecal coliform bacteria
GIS	Geographic Information Systems
GPS	Global Position System
Km	Kilometer
Km^2	Square Kilometer
LDD	Land Development Department
LQ	Land Quality
LU	Land Use
LU/LC	Land Use /Land Cover
LUR	Land Use Requirement
LUT	Land Use Types
MCA	Multi-Criteria Analysis
MCDM	Multi-Criteria Decision Making
MCE	Multi-Criteria Evaluation
MRA	Multiple regression analysis
NO_2	Nitrite
NO_3	Nitrate
NH_3	Ammonia
NPS	Non point source pollution
PS	Point source pollution
RS	Remote Sensing
TS	Total solid
SS	Suspended solid
SLB	Songkhla Lake Basin
TEMP	Temperature
TP	Total phosphorous
TCB	Total coliform bacteria
TUR	Turbidity
UNWWDR	United Nations’ World Water Development Report
US-EPA	United States Environmental Protection Agency
URB	U-tapao River Basin
WHO	World Health Organization

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

CONTENTS (continued)

PAGE

LIST OF TABLES

Tables **PAGE**

TABLES (continued)

Tables **PAGE**

LIST OF FIGURES

Figures **PAGE**

FIGURES (continued)

Figures **PAGE**

FIGURES (continued)

FIGURES (continued)

FIGURES (continued)

Figures **PAGE**

CHAPTER 1

INTRODUCTION

Background

Globally, human population is increasing at unprecedented rate. This has created a tremendous stress on local, regional, and global environment (Deng et al., 2008; Chakrabarty, 2001). Industrialization and urbanization have brought prosperity, and at the same time, have resulted in many environmental problems (Deng et al., 2008). Fast increasing population in developing countries in recent years has become one of the reasons to raise the demand for food and fuel (Food and Agricultural Organization of United Nations [FAO], 1986). It is believed that population growth, urbanization, and industrialization are major causes of changing land use pattern of society (Chakrabarty, 2001) and water quality of river system (Sliva & Williams, 2001). Therefore, the changing pattern of land use is one of the major driving forces in global environmental changes and essential debate of sustainable development (Lambin et al, 2000).

Many studies have shown that land use has a strong impact on water quality, and significant correlations exist between water quality parameters and types of land use (Ahearn et al., 2005; Basnyat et al., 1999; Elzabeth & Machiwa, 2004; Li et al., 2009; Sliva & Williams, 2001; Tong & Chen, 2002; Tu & Xia, 2006). The impacts of land use on water quality found in previous studies mentioned that human activities like agricultural, forest management, industrial and residential wastes discharge are very much related to water quality (Basnyat et al., 1999; Duh et al., 2008; Sliva & Williams, 2001). Generally land use types are related to economic activities and these developments have adverse impacts on water quality as well (Fisher et al., 2000). In other words, higher percentages of these developed land uses are related to higher concentrations of water pollutants. In contrast, negative relationships are usually found between percentages of undeveloped lands and concentrations of water pollutants, indicating that undeveloped lands are usually related to good water quality (Tu, 2011).

Increasing population, developmental pressures, high demand of limited land resources, competition on water resources, and lack of land use planning continually contribute to the degradation of water quality of river (Callender & Rice, 2000). Agricultural areas occupying larger portion of landscape are one of the important sources pollution when rainfall caries sediment, nutrients, or chemicals to rivers (Clausen & Meals, 1989). Urban development is also one of the causes of substantial modification to flood runoff timing and volume. Urban areas are rapidly changing by local and global forces and are often beyond the control (Deng et al., 2008). It is very urgent to develop an effective land use management system to manage the changing pattern of land use structure for sustainable development of the society (Pornipaatepong et al., 2010). Sustainable development has become widely recognized goal for human society as deterioration of environmental and social conditions in many areas of the world continues (Deng et al., 2008). Since, sustainable development means taking care of ecological, social, and economic aspects of development; it also includes the conservation of resources for the future generation. Therefore, integrating land use planning with water quality management will be a major player in sustainable development and the society will benefit from socio-economic development as well as environmental protection.

Identification of problems

The U-tapao river, located in southern part of Songkhla Lake Basin, Thailand, is an important water resource for people living in this area. Over the last ten years, combination of different factors affected the water quality of U-tapao river and turned to a polluted habitat and thus altering river ecosystem. Some of the major causes of this pollution are: rapid, unplanned urban and industrial expansions, domestic and industrial waste discharge into the river and other non-point pollution such as run-off from streets and highways (Gyawali et al., 2011c). Untreated domestic wastewater, frequent flooding and street runoff all contribute to water quality deterioration for waterways, which have been affecting environment and socio-economic structure of the basin. Besides these, liquid wastes from wide variety of industries located on the banks are being directly discharged into the river without proper treatment. Obviously, the river has been adversely affected by these discharges (Gyawali et al., 2012c). In addition, the lower section has experienced urbanization over the past three decades as the cities of Hatyai and Songkhla have grown and developed (Gyawali et al., 2012a). Given the reasons, the water quality of the U-tapao river is expected to continue to deteriorate in future.

Increasing population and enhancing urbanization processes are converting softer green spaces of a river basin into impermeable hard concrete surfaces. The changing pattern of agricultural land to urban settlement has impacted negatively on the ecological integrity and hydrologic process in the basin. In U-tapao river basin, the population and the pressure on land are ever increasing and current land use systems are not sustainable as they contribute to the problems of land degradation (Gyawali et al., 2012c). Therefore it is important to make a wise assessment of the land suitability for U-tapao river basin for sustainable development. The sustainable land use planning, therefore, involves the decision of land use so that the available resources are identified and utilized (Chen et al., 2005). Current land use planning in U-tapao river basin is not based on land assessment, therefore, there is a need to use land in most rational way by suitability matching current land types and land uses. Land suitability evaluation is always done by considering the principles of sustainability of land resources which help in preventing land degradation and further generates maximum possible output with minimum resources. In conclusion, the main problems of U-tapao river basin are the deteriorating water quality of river, changing agriculture land to urban land and increasing population. And, these problems could be managed by implementation of effective land use planning in basin level.

Research Objectives

Evaluation of land use planning is a challenging issue. It is necessary to develop effective decision making tool for evaluation of land use planning on environmental basis for sustainable development. This study aimed to develop specific technique to evaluate land use planning on the basis of water quality framework.

Specific Objectives

1. To find the relationship of land uses and water quality
2. To prepare land use planning map on the basis of land suitability
3. To evaluate land use planning on water quality framework

Conceptual framework

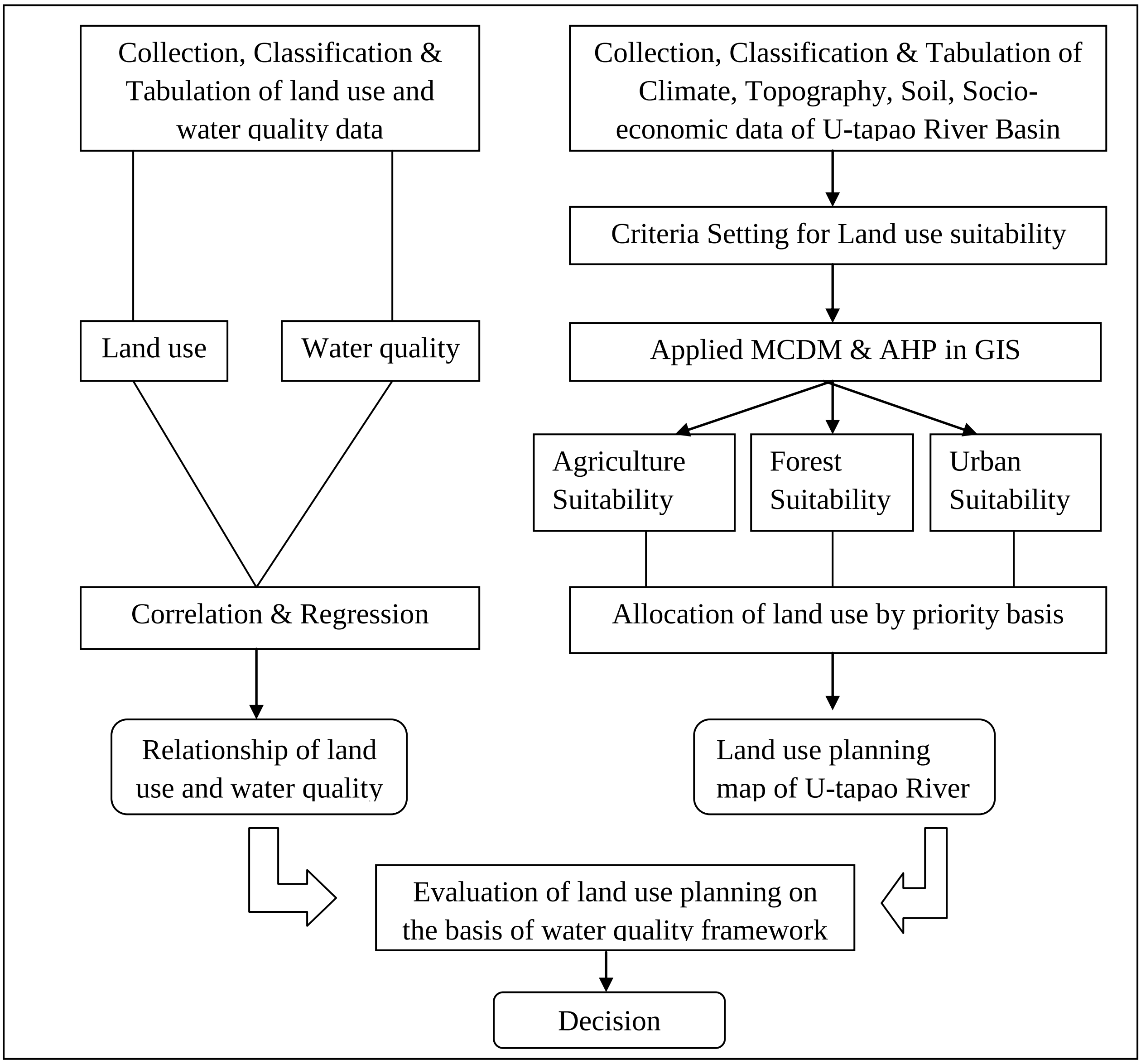


Figure 1. Conceptual Framework of the Study

Significances of the Study

Despite the extensive research performed on water quality issues (Admu & Nabegu, 2011; Bagalwa, 2006; Kuppusamy & Giridhar, 2006; Shrestha & Kazama, 2007), only limited studies have focused on U-tapao river basin (Sirtnawin & Sompongchaiyakul, 2005) and this study tried to link land use patterns of the basin with water quality of river and to develop predicting a model for water quality. Many previous studies have established the predicting models for water quality parameters by the combination of various land uses (Amiri & Namane, 2008; Azyana & Norulaini, 2012; Lie et al., 2008; Nakane & Haidary, 2010; Tu & Xia, 2006; Zampella et al., 2007) and current methods on predicting water quality in river based on land-use patterns are still in their developmental phase. In the case of U-tapao river basin, from extensive literature survey, no previous studies have ever been done to establish the relationship of land use patterns and water quality parameters. Therefore, this study tried to establish the relationship of land use patterns with water quality parameters by using existing methodology in new study area. This approach will be beneficial to other researchers who want to link land use and water quality in U-tapao river basin as well as other similar river basins. Results of the study will also amplify our understanding of the water quality of the river as well as land use. It also suggests actions which could be taken to mitigate impacts and improve the water quality in the watershed.

Identification of potentiality or suitability of land uses is a very important aspect for land use management. Generally, suitability analysis of agriculture has been done in many parts of the world (Tienwong et al., 2009; Thapa & Murayama, 2007; Mustafa et al., 2011). Even though the dominating land use of the U-tapao basin is agriculture, there are no suitability studies on agriculture in the U-tapao river basin. This study has developed land use suitability map of river by using MCDM in GIS environment. Applying this concept, land use suitability maps of different crops can be generated. This study also forwarded the concept of land use planning by allocating land suitability of agriculture and urban by protecting forest and water body. Land use planning can be generated in other basins or regions by allocating the land use suitability concept. Besides these, this study tried to develop the effective technique to evaluate the land use planning on water quality framework and this technique is very flexible and can be extended to other sectors with some modification.

In short, the information derived from this study can have direct application values to planners and policy makers for defining the impacts of land use on water resources and for implementing long-term planning and management schemes. The results of this study might be useful to those researchers who are interested in land use and water quality issues as well as land use planning of the U-tapao river basin. Therefore, this study provides the holistic view of land use planning by considering the environmental, social and economic issues and it is a new approach of planning for sustainable development of river basin.

Thesis Organization

As this thesis has different sections, the summary for each section is given below to help readers identifying the content.

First chapter: It includes background, identification of problems, research objectives, conceptual framework, and significance of the study.

Second chapter: It includes review of literature of surface water quality management, sustainable development concept, land use planning and suitability analysis, Multi Criteria Decision Making (MCDM) and Geographic Information Systems (GIS).

Third chapter: It includes details of study area.

Fourth chapter: It includes research methodology section of land use and water quality aspects.

Fifth chapter: It includes results and discussion of land use and water quality issues.

Sixth chapter: It includes research methodology aspect of land use suitability analysis of agriculture, forest and urban aspect of the basin by using MCDM & AHP in GIS environment.

Seventh chapter: It includes results and discussion of land use suitability analysis and land use planning of U-tapao river basin.

Eighth chapter: It includes five different types of scenarios regarding land use planning maps and decision making supporting tool of evaluating land use planning.

Ninth chapter: It includes conclusions, recommendations, limitation of this research and future research

CHAPTER 2

LITERATURE REVIEW

Background

Rivers, one of the most valuable natural resources on earth, have been utilized by mankind for domestic and agricultural purposes for thousands of years with only few of them being in their natural conditions (Nakane & Haidary, 2010; Ngoye & Machiwa, 2004). Along with the rapidly growing urbanization and industrialization, different activities like unplanned construction and encroachment, clearing of riparian vegetation along the banks, disposal of waste materials, and unwise mining activities on the rivers are seriously degrading river ecological system (Duong et al., 2006; Bagalwa, 2006; Azyana & Norulaini, 2012). There is no doubt that anthropogenic activities are directly or indirectly related to the increment of pollution of river and polluted river causes not only the deterioration of water quality but also threatens human health and the balance of aquatic ecosystems, economic development, and social prosperity (Milovanovic, 2007). Generally, water quality of river is degraded from point sources and non-point sources pollution; point sources pollutants are directed and released into water bodies in man-made pipes whereas non-point source pollutants are washed from the earth’s surface by storm runoff and enter water bodies of their own accord (Amiri & Nakane, 2008; Meynendonckx et al., 2006; Tong & Chen, 2002; Sliva & Williams, 2001).Compared to causes of point sources pollution, non-point sources pollution are more complicated to understand (Shrestha et al., 2011; Yang et al., 2007; Bahar et al., 2008; Yang & Jin, 2010; Ahearn etal.,2005; Sliva&Williams, 2001).

However, it is claimed that land use plays an important role in determining non-point source pollution. Therefore, changes in land use and land management practices are primarily responsible for the alteration of receiving water quality and quantity (Ahearn et al., 2005). As water drains from the land surface, it carries the residues from the land. As a result, the quantity of water available for runoff, stream flow and ground water flow, as well as the physical, chemical, and biological processes in the receiving water bodies can be affected (Xian et al., 2007). Land use of a given region might influence hydrological processes of the basin. Land use changes can cause floods, droughts, and changes in river and groundwater regimes, and they can affect water quality. It is, therefore, conceivable that there is a strong relationship between land use types and the quantity of water (Sliva & Williams, 2001). If land use changes in the future, the levels of contamination will be changed accordingly. Many studies demonstrate that surface water quality has degraded noticeably in many parts of world due to poor land use practice (Li.et al., 2009; Zampella et al., 2007) and there seem significant correlations between water quality parameters and land use types (Wali et al., 2002; Tu, 2011; Azyana & Norulaini, 2012).

This study has focused on water quality of U-tapao river and a greater emphasis in this literature has been given to rivers and streams, not lakes or other holding structures such as reservoirs. The study does not examine the impacts of land use change on groundwater. It is predicted or expected that water quality of river can be avoided through planning by making proper allocation of land use activities consistent with the principles of sustainable development (Gove et al., 2001). Therefore, a brief introduction of sustainable development has also been explained in this chapter. Another purpose of this study is to develop the effective land use planning of the basin by considering the impact of land uses on water quality. For effective land use planning, policy or decision makers mostly follow the land use planning guidelines of FAO. For this reason, in this chapter, meaning and definition land use planning, the planning process, FAO guidelines of land use planning and the concept of integrated land use planning are briefly explained. FAO has mentioned the procedure of evaluation of land use. For effective evaluation of land use, the suitability analysis of land use has to be done. By following the concept of land use suitability analysis of FAO, the study has successfully prepared the suitability maps of agricultural, forest and urban areas of the basin. Therefore, the methodology of suitability analysis is also briefly explained in this chapter.

Water Quality Management

Water is an important element of all living beings. Despite the fact that 70% of the earth’s surface is covered by water, only 2.5% of that water is fresh and only 0.3% of that water is available for human use (United Nations’ World Water Development Report [UNWWDR], 2003). Furthermore, pressures on this resource are increasing. Currently, it is estimated that around 54% of all accessible freshwater is contained in rivers, lakes and underground aquifers and by 2025 this will increase to 70%. If per capita consumption of water resources continues to rise at its current rate, humankind could be using over 90% of all available freshwater within 25 years, leaving just 10% for all other living beings (Goldar & Banerjee, 2004).

World Health Organization (WHO) pointed out 15 threats to sources of drinking water and aquatic ecosystem. These include: waterborne pathogens; algal toxins and taste and odor problems; pesticides; persistent organic pollutants and mercury; endocrine disrupting substances; nutrients; aquatic acidification; ecosystem effects of genetically modified organisms; municipal waste water effluents; industrial point source discharges; urban runoff; landfills and water disposal; agricultural and forestry land use impacts; natural sources of trace element contaminants and impacts of dams, diversions and climate change (Emmerth & Bayne, 1996).

In most developing countries, water pollution is a major reason of communicable human diseases, misery and death. According to the WHO, about 4 million children die every year as a result of diarrhea caused by water-borne infection. The bacteria most commonly found in polluted water are coliforms excreted by human. Surface runoff and consequently non-point source pollution contributes significantly to high level of pathogens in surface water bodies. Improperly designed rural sanitary facilities also contribute to contamination of groundwater. In some regions, natural geology or soils contain high background concentrations of phosphorus and arsenic, threatening human and ecosystem health (Arnold & Gibbons, 1996). Water quality varies depending on natural background or the degree of development. Urban and industrial development, accompanied with higher wastes inputs from factories, transportation, typically contribute to water pollution (Bledsoe & Watson, 2001). The population in the basin has been growing fast hence increasing the risk of pollution to this water resource. Water quality in rivers is generally linked with land use in the watershed that can affect the amount and quality of runoff during and following rainfall. Forestry, agriculture, industrialization and urbanization modify watershed characteristics that influence runoff quality and quantity (Schuler, 1994). Many problems of water pollution are caused by changes in land-use patterns on catchment areas as population pressure and economic activity increase (Goldar & Banerjee, 2004).

Sources of Water Pollution

Water pollution is generally classified into two categories, namely, point source (PS) and nonpoint source (NPS). Point source pollutants are directed and released into water by man-made structures. For instance, effluents from industries and wastewater treatment plants are point source pollutants. Non-point sources of water pollution come from a wide group of human activities for which the pollutants have no obvious point of entry into receiving watercourses (Tong & Chan, 2002; Sliva & Williams, 2001). Non-point source (NPS) pollution is typically caused by rainfall or snowmelt moving over or through the ground, carrying up natural and human pollutants, and picking those pollutants into surface waters (Banadda et al., 2009). Non-point source pollutants are excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas, bacteria and nutrients from livestock and faulty septic systems, oil grease, and toxic chemicals from urban runoff and energy production, sediment from improperly managed construction sites, crop and forest lands, salt from roads and irrigation practices, and acid drainage from abandoned mines (Davis & Masten, 2004). These pollutants ultimately find their way into groundwater, wetlands, rivers and lakes and finally, to oceans in the form of sediment and chemical loads carried by rivers and the ecological impact of these pollutants range from simple nuisance to severe.

Unlike point sources pollution like industrial and sewage treatment plants, nonpoint pollution sources are difficult to monitor and regulate because of their diffusive nature (Yang & Jin, 2010). Furthermore, NPS pollution impacts at a larger scale but generally at lower concentrations, making pollution sources difficult to identify. Although NPS pollutants tend to occur in lower concentrations than PS pollutants, the environmental impact they cause can be just as severe (Alkharabshs & Taanay, 2003). Obviously, non-point source pollution is much more difficult to identify measure and control than point sources (Goldar & Banerjee, 2004). Consequently, non-point source pollution is a major problem for surface waters because often times it is difficult to identify the source of the pollution. Therefore, control of non- point sources of pollution is problematic.

United States Environmental Protection Agency (US-EPA, 1994) identified that agriculture was the leading cause of water quality impairment of rivers and lakes in the United States (Table 1).

Table 1
Leading sources of water quality impairment in the United States

Rank	Rivers	Lakes	Estuaries
1	Agriculture	Agriculture	Municipal-point sources
2	Municipal point sources	Urban runoff/storm sewers	Urban-runoff/storm sewers
3	Urban runoff/storm	Hydrologic/habitat modification	Agriculture
4	Resource extraction	Municipal point sources	Industrial point sources
5	Industrial point sources	On-site wastewater	Resource extraction

Source: United States Environmental Protection Agency (1994)

Around 72% of assessed river length and 56% of assessed lakes are impacted by agricultural activities in USA (Table 2). From these figures, US-EPA declared that agriculture is the leading source of impairment in the nation’s rivers and lakes. European countries also give emphasis on non-point sources pollution on water. They are very much concerned on the increased level of nitrogen, phosphorus, and pesticide residues in surface and groundwater. Intense cultivation and livestock operations are major agricultural non-point sources pollution to surface and groundwater pollution. In a recent comparison of domestic, industrial and agricultural sources of pollution from the coastal zone of Mediterranean countries, United Nations Environment Programme-World Conservation Monitoring Centre (UNEP-WCMC, 2009) found that agriculture was the leading source of phosphorus compounds and sediment.

Table 2
Percent of assessed river length and lake area impacted

Source of pollution	Rivers (%)	Lakes (%)	Nature of pollutant	Rivers (%)	Lakes (%)
Agriculture	72	56	Siltation (sediment)	45	22
Municipal-point sources	15	21	Nutrients	37	40
Urban-runoff/storm sewers	11	24	Pathogens	27	
Resource extraction	11		Pesticides	26	
Industrial point sources	7		Organic-enrichment DO	24	24
Silviculture	7		Metals	19	47
Hydrologic/habitat modification	7	23	Priority organic chemicals		20
On-site-wastewater disposal		16			
Flow modification		13			

Source: United States Environmental Protection Agency (1994)

Major causes of deteriorating water quality

Agriculture

Agricultural activities are considered as the leading causes for degradation and pollution of aquatic systems (Gove et al., 2001) and also dominant component of global economy. It is well known that agriculture is the single largest user of freshwater resources, using a global average of 70% of all surface water supplies. Agriculture uses two-thirds of the world's water and is the greatest source of livelihood, especially in the developing world where large portions of the population depend on farming to meet daily survival needs (Clausen & Meals, 1989). Reports from across the globe have shown that agriculture is a chief contributor to water quality degradation by runoff carries fertilizers, herbicides, pesticides, and livestock waste in drainage into tributaries, which carry of the runoff into major water bodies (Deng et al., 2008). United States Environmental Protection Agency (2000) reported that agriculture non point source pollution (NPS) is the leading source of water bodies deteriorating (US-EPA, 2000). Poorly managed animal feeding operations, overgrazing, too often plowing, and improper, excessive, or poorly timed application of pesticides, irrigation of water and fertilizers are the causes of NPS pollution. Therefore, agriculture based water pollution is becoming a major concern not only in developing countries but also in developed countries (Wang, 2001). However, agriculture is both the cause and victim of water pollution. It is a cause through its discharge of pollutants and sediment to surface and/or groundwater and it is a victim through use of wastewater and polluted surface and groundwater which contaminate crops and transmit disease to consumers and farm workers. Anyway, agriculture, as a single largest user of freshwater on a global basis and as a major cause of degradation of surface and groundwater resources through erosion and chemical runoff, has a cause to be concerned about the global implications of water quality (Clausen, & Meals, 1989).The associated agro-food processing industry is also a significant source of organic pollution in most countries. Aquaculture is now recognized as a major problem in freshwater, estuarine and coastal environments, leading to eutrophication and ecosystem damage (Ribbe et al., 2009).

Agriculture represents a large portion of the land use in the river basin. Runoff from these lands could have a major impact on the water quality of the river. Therefore, appropriate steps must be taken to ensure that agricultural activities do not adversely affect water quality so that subsequent uses of water for different purposes are not impaired (FAO, 1997) and FAO recommended some action plans to improve water quality as:

- Establish operational cost-effective water quality monitoring systems for agricultural water uses.
- Prevent of adverse effects of agricultural activities on water quality for other social and economic activities through optimal use of on-farm inputs and the minimization of the use of external inputs in agricultural activities.
- Establish biological, physical and chemical water quality criteria for agricultural water users
- Prevention of soil runoff and sedimentation.
- Proper disposal of sewage from human settlements and of manure produced by intensive livestock breeding.
- Minimization of adverse effects from agricultural chemicals by use of integrated pest management.

- Education of communities about the pollution impacts of the use of fertilizers and chemicals on water quality and food safety.

The major pollutants arising from agricultural lands are nutrients, particularly nitrogen and phosphorus, pesticides, sediment, pathogens, and endocrine disrupting substances. The presence of these substances can make water unfit for use by human, and can destroy habitat as well (Xian et al., 2007).

Nutrients: Nutrients are chemical substances that provide nourishment and promote growth of microorganisms and vegetation. They include nitrogen, phosphorus, carbon, hydrogen, oxygen, potassium, sulfur, magnesium and calcium. The addition of nutrients to an aquatic or terrestrial ecosystem increases the biomass of plants and, ultimately, decreases the number of species. Generally, agriculture and forestry get the benefits from added nutrients, but natural ecosystems generally suffer an undesirable change in plant and animal communities. Nutrients from sewage and agricultural sources have long been recognized as pollutants of aquatic ecosystems (Braskerud, 2002; Carpenter et al., 1998; Jarvie et al, 1998).

Pesticides: Pesticides are the primary means of control of weeds, insects and diseases that affect animal and crop production. Surface runoff, spray drift, and direct overspray from agricultural and urban lands are important pathways for introducing pesticides to surface waters and due to modern agriculture practices, the impact of agricultural pesticides is very severe for ecosystem of water bodies around the world (Emmerth & Bayne, 1996).

Sediments: Much of the increased sediment load to streams arises from agricultural practices such as livestock access to streams. These practices increase erosion and the movement of soil from farmland into adjacent waters. Much of the phosphorus and pesticide losses from farm land to surface water are bound to eroded soil particles. Suspended sediments increase turbidity which results decrease in light available for photosynthesis and affect many levels of biological organization. Therefore, anthropogenic erosion and sedimentation is a global issue that tends to be primarily associated with agriculture and it is believed that it is global sediment supply to rivers, lakes, estuaries and finally into the world's oceans (Emmerth & Bayne, 1996; Daniel et al., 2002; Even et al., 2004).

Pathogens: Pathogen contamination of aquatic ecosystems is known to occur from a range of sources including municipal waste water effluents, agricultural wastes, and wildlife. The World Health Organization (WHO) has stated that infectious diseases are the world's single largest source of human mortality. Many of these infectious diseases are waterborne and have tremendous adverse impacts in developing countries. Waterborne pathogens also pose threats to recreational waters resulting in illnesses and economic impacts on local communities. Another critical aspect of waterborne disease is the threat that pathogens pose to aquatic ecosystems and biodiversity. Infectious diseases are strong biotic forces that can threaten biodiversity by causing population declines and accelerating extinctions (Kuhn et al., 1997; Emmerth & Bayne, 1996).

Endocrine Disrupting Substances: Internationally, there is growing concern about environmental risks posed by endocrine disrupting substances (EDS). These systems can be affected by a number of chemicals, including a wide variety of environmental contaminants such as polychlorinated biphenyls (PCBs) and organochlorine pesticides, which can exert a diverse array of effects on growth, development and reproduction in biota. Intensive agriculture and municipal waste water effluent are two major sources of EDS in the environment (Emmerth & Bayne, 1996).

Table 3
Agricultural impacts on water quality

Agricultural Activity	Impacts	
	Surface water	Ground Water
Tillage/ Ploughing	Sediment/ turbidity/Siltation	
Fertilizing	Runoff of Nutrients	Leaching of Nitrate
Manure spreading	Pathogens, Metals, Phosphorus and Nitrogen	Contamination by Nitrogen
Pesticides	Endocrine Disrupting Substances (EDC)	EDC
Irrigation	Salinity	Salts, Nitrate
Aquaculture	EDC	

Urbanization

The global population in urban areas is growing at an unprecedented rate (Bledsoe & Watson, 2001). Urbanization has brought rapid changes to urban spatial structure and greatly increased the amount of stress, in the form of waste and pollutants, on the ecosystem. These changes have significantly and adversely affected water quality (Wang, 2001). Urbanization affects the environment in many ways. For instance, urbanization has been associated with introduction of exotic species, modification of landforms and drainage networks, control or modification of natural disturbance agents, and the construction of extensive infrastructure (Mander et al., 1998). With rapid rates of urbanization, sudden and unexpected changes in environmental quality may be the cause to unpredictable declines in health of urban residents. Another problem of urbanization is altering the hydrology system. As the natural landscapes are altered, the percentage of land covered by impervious surface increases. Impervious surfaces can cause serious hydrologic alterations (Arnold & Gibbons, 1996). These surfaces prevent natural pollutant processing by decreasing infiltration and increasing surface runoff, which increases to peak discharges and flood magnitudes (Chakrabatay, 2001).

Increment of urbanization is very much related with municipality waste which is a complex mixture of human waste, suspended solids, debris and a variety of chemicals derived from residential, commercial, and industrial sources (Banadda et al., 2009). Pollution from municipal sewage is considered to be point source and the impact of municipal sewage is directly observed in river system. Materials contained in municipal waste water effluents that have a negative effect on aquatic ecosystems include: waste materials, nutrients, endocrine disrupting substances etc. (Daniel et. al., 2002). Since, municipality waste represents point source pollution, with effective management they are relatively simple to monitor, regulate and it can often be controlled by treatment at the source because the source can be readily identified (Ren et al., 2003).

Industrialization

Industrialization is considered to be the cornerstone of development strategies due to its significant contribution to the economic growth and human welfare, but it carries inevitable costs and problems in terms of pollution of the air and water resources (Kannj & Achi, 2011). Worldwide water bodies are the primary means for disposal of waste, especially the effluents, from industries that are near them. These effluents from industries have a great deal of influence on the pollution of the water body; can alter the physical, chemical and biological nature of the receiving water body (Yang et al., 2003). Specially, water bodies near the industrial area have been extremely affected from disposal of waste which can alter the physical, chemical and biological nature of the receiving water body. Therefore, industrial waste is the most common source of water pollution in the present day and it increases yearly due to the fact that industries are increasing because most countries are getting industrialized (Osibanjio et al, 2011). Industrial waste-water originates from the wet nature of industries which require large quantities of water for processing and disposal of wastes. Most industries are therefore, located near water sources (Adekunle et al., 2010). Due to lack of systematic planning and control mechanism, industries have been creating a lot of problems in the water system (Yin et al., 2005).

Deforestation

The human impacts on the forest for agriculture, cattle ranching or urban expansion cause changes on water resources. Deforestation is understood as the net conversion from forest to non-forest land cover. Generally, it is believed that existence of forest near water body is very helpful for water quality. Due to increment of population and industrialization, deforestation rate has been increasing globally. This pattern will create problem not only in water quality of rivers or lakes, but also in all socio-economic and environmental structures of globe. It also affects bio-diversity as well as land use structure. Mostly deforestation creates huge amount of soil erosion, ultimately through sedimentation, thereby affecting the quality of water bodies (Basnayet et al., 1999; Hess et al., 2006).

Land Use Management

The land use is the product of human decision operating within social, political and legal frameworks (Cruz, 2005). For land use management, two terms, “land use” and “land cover” are very much confusing and considered as the synonymous. In general, land use refers to results of human activities, while land cover refers to the attribute of natural cover including vegetation, topography, soil, surface, and groundwater, as well as artificial construction on the earth surface (Lambin et al., 2000). Land use change, is the physical change in land cover caused by human activities such as agriculture, and is a common phenomenon associated with population growth, market development, technical and institutional innovation, and related rural development policy. Land cover changes are linked to the change of weather and climate in many ways, as well as to human livelihoods and environmental components such as air quality and water supply (Finkenbine et al., 2000). In this study, land use is expressed in a broad sense, including both land use and land cover.

Urban (or Built-up) Land Use: Urban land includes areas of intensive use where a significant percent of the land is covered by impervious materials (e.g. buildings, pavement, etc.). This type of land use includes: residential, commercial, industrial, transportation, communications and utilities, industrial complexes, mixed urban areas etc. So, urban land cover includes land covered by cities, towns, villages, strip developments, transportation components, power facilities, communications structures, malls, shopping centers, and industrial and commercial complexes. Urbanization means the changing land cover types from permeable land to anthropogenic impervious surfaces (Christodoulou & Nakos, 1990). By urbanization, impervious surfaces might increase and can alter the natural hydrological condition by increasing the volume and rate of surface runoff and decreasing ground water recharge and base flow. This eventually leads to larger and more frequent local flooding and reduced water supplies for urban and suburban areas (Harbor, 1994).

Agriculture Land Use: Agriculture land use includes crop and livestock production, plant nurseries, orchards, vineyards, and other land-based growing activities. This category also includes buildings necessary to conduct agricultural activities which are used for various types and direct farm related businesses. Agricultural lands are also important for their aesthetic values, and the preservation of open space is a major goal of this plan. In global scale, increasing population density has forced agricultural production to expand into upland areas. This trend resulted in decreasing forest resources with associated soil erosion and resource degradation (Helmer, 2004).

Forest Land Use: Forest lands are primarily wooded or forested. The forest land category includes areas to be used primarily for timber harvesting, wildlife habitat, hunting, and certain forest-related outdoor recreational activities. Intensive recreational uses such as shooting ranges, driving ranges, campgrounds, recreational resorts, and commercial hunting or game reserves may be allowed where compatible with adjacent land uses. Wet lands and open green space are also included in forest land category (Chinea & Helmer, 2003). Due to increment of population and urbanization, land use change caused by urban sprawl has been putting great pressure on the undeveloped land. Therefore, undeveloped land, mainly forest, has been converted into developed land, especially residential land due to the rapid urban sprawl (Helmer, 2004) leading to the main problem of land use management for sustainable development.

Water body: Generally, water body means the land which is covered by natural or artificial water like river, stream, lake, reservoir in earth surface. The area of water body in the earth is minimum compared with other land uses, but it is very important for human survival. From environmental point of view, protection of water is an important task for land use management for sustainable development (Langebein & Iseri, 1995).

Relationship between land use and water quality

Surface water is one of the most important components in human life and it is used for many purposes. But, this valued resource is being threatened as human population growth increases the demand for more water of high quality for domestic and economic activities (Eni et al., 2011). The quality of surface water has deteriorated in many countries in the past few decades due to changing land use pattern around the world (Lee et al., 2009; Rothenberger et al., 2007; Uriorte et al., 2010; O'Driscall et al., 2010). Natural processes and both direct and indirect effects of human activities are major drivers of land use and land cover change. Land use changes are directly affected on water quality streams, rivers, and lakes which are an important part of the landscape, as they provide water supply, recreation, and transportation for humans, and a place to live for a variety of plants and animals.

Agriculture Vs water quality

Agricultural land cover includes land used for production of food and fiber. Reports from across the globe have shown that agriculture is a chief contributor to water quality degradation by runoff carried fertilizers, herbicides, pesticides, and livestock waste in a drainage basin into tributaries, which carry the runoff into major water bodies (Deng et al., 2008). The intensification of agricultural practices, in particular the growing use of fertilizers and pesticides are major causes of deteriorating water quality. Poorly managed animal feeding operations, overgrazing, plowing too often or at the wrong time, and improper, excessive, or poorly timed application of pesticides, irrigation water and fertilizers are the causes of non point source pollution. Eventually, the changing agriculture land uses also change the levels of contaminants of river system (Mahvi et al., 2005).

Urban Vs water quality

Even though urban areas cover a relatively small proportion of the earth, these areas contain much of the world's population and can have significant ecological impacts on water quality. During the last few decades, there has been a significant shift in global land use towards urban land uses, with increases in both residential and other urban uses. Most of the shifts in land use were from agriculture or forests to urbanized areas. Even though urbanization has brought rapid changes in human life, it has greatly increased the stress, in the form of waste and pollutants, on the ecosystem (Ahearn et al., 2005). Urbanization is one of the fastest growing land use transformation which is one of the major causes of decreasing the quality of river ecosystem (Ho et al., 2003; Moscrip & Montgomery, 1997; Pompeu & Alves, 2005; Wang et al.; 2011). In addition, land-use change in urban areas not only decreases the area of the vegetation but also enlarges the ratio of the impervious areas and changes the hydrology of the basin (Pompeu & Alves., 2005). The negative effects of urbanization on watershed hydrology have been recognized for many years (Kearns et al., 2005). Continued land development and land-use changes within cities and at the urban fringe present considerable challenges for environmental management (Samat, 2006).

It has been found that the unplanned urban and industrial expansions and domestic and industrial waste discharge are having a direct impact on the water quality of the lakes and rivers. Many previous researches have established the relationship of urbanization and water quality. For instance, Eni et al., (2011) have found that urban land and other urbanization indicators were highly positively correlated with the water quality indicators during a research on the effects of urban land use change on water quality in Calbar Municipality, Nigeria. In China, Shanghai, Yin et al. (2005) used built-up land surface to investigate the relationship between urbanization patterns and water quality. They found strong correlations between developed land, population density, and water quality, where contributions of untreated domestic wastewater and non-point pollution were majors' causes of polluting nearby waterways.

Industry Vs water quality

Industrialization is also considered the cornerstone of development strategies due to its significant contribution to the economic growth and human welfare, but it carries inevitable costs and problems in terms of pollution of the air and water resources (Kannj & Achi, 2011). Specially, water bodies near to industrial area have been extremely affected from disposal of waste which can alter the physical, chemical and biological nature of the receiving water body (Gyawali et al., 2012b) resulting in the most common source of water pollution in the present day and it keeps on increasing yearly due to the fact that industries are increasing

(Osibanjio et al., 2011). Industrial waste contamination of natural water bodies has emerged as a major challenge for developing counties. As a result, water bodies which are major receptacles of treated and untreated or partially treated industrial wastes have become highly polluted.

Forest Vs water quality

Generally, forest has minimal effects on water quality. In areas covered by forests and rangeland the terrestrial and aquatic environments are in dynamic equilibrium. Rainfall is absorbed by the land surface and vegetation and released over a long period of time. There is little surface runoff during periods of normal rainfall and few nutrients are carried away in drainage waters. Many studies have shown that water in forested areas has lower levels of nutrients than water closer to human activities (Basnyat et al, 2000; Ngoye & Machiwa, 2004).

Deforestation and forest degradation are the most important land use change processes in the world. In the many parts of the world, economic shifts away from agriculture to industrialization lead to decrease in forest cover area. Therefore, urban expansion brings with it concern over loss of agriculture or forest lands and associated wildlife, loss of cultural or aesthetic value. In the tropical regions, rapid and diverse land cover changes occur on the forest and agriculture lands. These types of shifting found on industrial and service dominated economy leads to rapid urbanization (Islam & Sato, 2012).

Sustainable Development

The idea of sustainable development grew from numerous environmental movements in earlier decades. The concept of ‘sustainable development’ was introduced by the United Nations World Commission on

Environment and Development (WCED) and it can be conceived of in a general sense as a process through which there is a satisfaction of human needs while simultaneously preserving the quality of the natural environment. The linkage between economic development and the natural environment was perhaps first acknowledged in 1980 when the International Union for the Conservation of Nature published a pamphlet entitled World Conservation Strategy that included the term “sustainable development” (IUCN,1980). The term, sustainable development, came into more general use following the publication of the Brundtland Commission report in 1987 (Brundtland Commission, 1987). The Brundtland Commission, which was formally known as the World Commission on Environment and Development, was created by the United Nations General Assembly.

The Brundtland Commission established the most commonly used definition of sustainable development, as development which “meets the needs of the present generation without compromising the ability of future generations to meet their own needs.” Sustainable development is a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for future generations. Therefore, sustainable development is based on socio-cultural development, political stability and decorum, economic growth and ecosystem protection and its main aim is to protect and enhance the environment by meeting basic human needs, promoting current and intergenerational equity and improving the quality of life of all people.

Furthermore, the United Nation (2001) states that the most common elements of sustainable development are; firstly, using and protecting the resources in such a way that the economic, cultural and social and physical environmental well-being of communities is sustained. Secondly, managing those resources in order to meet the foreseeable needs of future generations, to safeguard the life-supporting capacity of air, water, soil, and ecosystems (including the food-chain), and thirdly to avoid, remedy or mitigate adverse impacts of human activities on the resources.

The theme of sustainable development has no shortage of definition offered to define what is meant by sustainable. Fennell & Dowling (2003) argued that the sustainable development was seen as a guide to the management of all resources in a way that it could fulfill economic, social and needs while maintaining cultural identity, ecological process, biological diversity, and life support system. It also precedes the development in sustainable way such as promoting the preservation of natural resource and applying the sustainability in community development strategies and plans. FAO (1995) accepted the sustainable development objectives, and defined it as ‘the management and conservation of natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations’. Such sustainable development would conserve land, water, plant and animal resources and would lead to environmentally non-degrading, technically appropriate, economically viable and socially acceptable production systems (FAO, 1995). Moreover, sustainable development is a dynamic process which enables people no relies their potential and improve their quality of life in ways which simultaneously protect and enhance the earth’ life support systems.

Unfortunately these definitions have been difficult to implement in practice; consequently, it has been necessary to search for more particular definitions of sustainable development. It is now generally recognized that sustainable development does not focus entirely on the environment. The notion of sustainable development encompasses three primary areas: the economic, the social, and the environmental. As such, sustainable development can be said to rest on three fundamental principles: economic development, social development, and environmental protection.

The report of World Commission on Environment and Development

The report of World Commission on Environment and Development (WCED, 1987) identified a number of key principles including:

- Inter-generation equity- It means the range of activities and the scope of ecological diversity available to future generations is at least as broad as that felt by current ones
- Intra-generational equity, social justice and poverty alleviation- It is to improve the well-being of all residents in a community and does not just benefit the power or the rich.
- Public participation-it means people all share a role to play and communities need to collectively make decisions rather than having them imposed by external forces.
- Environmental protection as an integral component of economic development- Economic development without environmental conservation is no longer acceptable.
- Dealing cautiously with risk and uncertainty – In situations where environmental impacts of activities are not known, the preferred option is to proceed cautiously or not at all, until the likely impacts can be determined.
- Use of renewable resources at a rate equal to or less than the natural rate of regeneration.
- Accountability—it concerns setting clear standards, and ensuring, monitoring and enforcing them.

Sustainability

The concept of sustainability was also highlighted by the International Union for the Conservation of Natural Resources in 1980 at its World Conservation Strategy (IUCN, 1980). As there is no universally agreed way in which sustainability can be achieved, many different views spread over the world and also makes confusion when it is used as the synonyms of sustainable development. In general, sustainability is the destination, an end-state, and sustainable development is a means of getting there. It’s all about striking the right balance when making decisions, ensuring that our economic and social aspirations are achieved within environmental limits.

The concept of sustainability has been applied in different organizations and industries by developing own definition based on the UN idea. Sustainability is a concept and strategy by which communities seek economic development approaches that benefit the local environment and quality of life. Sustainable development provides a framework under which communities can use resources efficiently, create efficient infrastructures, protect and enhance the quality of life, and create new business to strengthen their economies. A sustainable community is achieved by a long-term and integrated approach to developing and achieving a healthy community by addressing economic, environmental, and social issues. Fostering a strong sense of community and building partnerships and consensus among key stakeholders are also important elements.

The United Nations Environment Program (2009) gives more explanation that sustainability principles refer to the environmental, economic, and socio-cultural aspects of development, and a suitable balance must be established between these three dimensions to guarantee its long-term sustainability; firstly, to make the optimal use of natural resources; secondly, to respect the socio-cultural of authenticity of host community, and thirdly to ensure viable, long-term economic operations, providing socio-economic benefits to all stakeholders that are fairly distributed.

In summary, “sustainability” is a systematic concept, related to the continuity of economic, social, institutional and environmental aspects of human society and non-human environment. It intends to be a means of configuring civilization and human activity so that society, its members and its economies are able to meet their needs and express their greatest potential in the present, while preserving biodiversity and natural ecosystems, and planning its ability to maintain in the long term; sustainability affects every level from the local neighborhood to the entire planet. Furthermore, sustainability is the ability to utilize local resources efficiently in the long-term by maintaining the ecosystem.

Agenda 21 and Sustainable Development

Agenda 21 is a program run by the United Nations (UN) related to sustainable development and it was the planet’s first summit to discuss global warming related issues. It is a comprehensive blueprint of action to be taken globally, nationally and locally by organizations of the UN, governments, and major groups in every area in which humans directly affect the environment. The full text of Agenda 21 was revealed at the United Nations Conference on Environment and Development (Earth Summit), held in Rio de Janerio on June 14, 1992, where 178 governments voted to adopt the program. The final text was the result of drafting, consultation and negotiation, beginning in 1989 and culminating at the two-week conference. The number 21 refers to an agenda for the 21st century. It may also refer to the number on the UN's agenda at this particular summit. In 1997, the General Assembly of the UN held a special session to appraise five years of progress on the implementation of Agenda 21 (Rio +5). The Assembly recognized progress as 'uneven' and identified key trends including increasing globalization, widening inequalities in income and a continued deterioration of the global environment.

Agenda 21 explains that population; consumption and technology are the primary driving forces of environmental change. It lays out what needs to be done to reduce wasteful and inefficient consumption patterns in some parts of the world while encouraging increased but sustainable development in others. It offers policies and programs to achieve a sustainable balance between consumption, population and the Earth's life-supporting capacity. It describes some of technologies and techniques that need to be developed to provide for human needs while carefully managing natural resources.

Agenda 21 provides options for combating degradation of the land, air and water, conserving forests and the diversity of species of life. It deals with poverty and excessive consumption, health and education, cities and farmers. There are roles for everyone: governments, business people, trade unions, scientists, teachers, indigenous people, women, youths and children. Agenda 21 does not shun business. It says that sustainable development is the way to reverse both poverty and environmental destruction.

A major theme of Agenda 21 is the need to eradicate poverty by giving poor people more access to the resources they need to live sustainably. By adopting Agenda 21, industrialized countries recognized that they have a greater role in cleaning up the environment than poor nations, who produce relatively less pollution. The richer nations also promised more funding to help other nations develop in ways that have lower environmental impacts. Beyond funding, nations need help in building the expertise with the capacity to plan and carry out sustainable development decisions. This will require transfer of information and skills.

Agenda 21 calls on governments to adopt national strategies for sustainable development. These should be developed with wide participation, including non-government organizations and the public. Agenda 21 puts most of the responsibility for leading change on national governments, but says they need to work in a broad series of partnerships with international organizations, business, regional, state, provincial and local governments, non-governmental and citizens' groups. Therefore, Agenda 21 is a comprehensive plan of action to be undertaken globally, nationally and locally. The extensive document covers social and economic issues, such as poverty, and environmental issues ranging from the protection of the atmosphere to the safe management of waste. The drive towards cataloguing diversity, identifying 'biodiversity hotspots' and highlighting the commercial value of ecological resources was a major task on under this concept.

Land Use Planning

Planning is a set of procedures, tools and instruments which is used to design and make decisions about what is to be done in the future. One can differentiate between formal planning and informal planning. Informal planning is a relaxed way of planning whereas formal planning is done by institutions and governments to achieve specific goals. Formal planning involves many stakeholders and should be considered as binding once a plan has been approved, and decision makers need to stick to it (FAO/UNEP, 1999).

There are many kinds of plans which are distinguished by their desired outcomes and their levels of intervention, for example development plans, strategic plans, action plans, operational plans, land use plans, environmental plans or construction plans. Other plans are distinguished by the areas they cover: national plans, regional plans, village plans, urban plans, rural plans, etc. Generally speaking, to plan means to carry out a sequence of actions with the intention to shape the future. Formal planning aims at designing developments in an organized and coordinated manner. It is a structured process which is guided by considering the following questions: What is the present situation? What is the situation we want to have? How do we reach that situation?

With the increasing demand for land, land use planning and land evaluation have become more important as people strive to make better use of the limited land resources (Jeon & Kim, 2000). In recent years, limited land resources in some countries could not meet increasing demands for land. In many developing countries, the demand for land becomes more pressing every year due to factors such as technical charge, economic development and population increase (Fafchamps & Quisumbing, 2002). According to the guidelines published by FAO, (1993) land use planning is the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the best land use options. The purpose of land use planning is "to select and put into practice those land uses that will meet the needs of the people best while safeguarding resources for the future" (FAO, 1993). Land use planning is applied to solve problems of conflicts between certain land use and sustainable environmental development. The 1987 Brundtland Commission Report promoted the concept of sustainable development, which was to become the central theme of the report. Reasonable land use planning procedures are basic prerequisites for successful long-term land use development. Land use planning needs an integrated procedure to achieve this objective.

On any given day in most cities and counties across the world, numerous land use planning proposals are introduced. Planning is often used by local governments to help generate efficient and sustainable development in various communities. It uses various techniques for managing the location and character of community expansion. Although planning is influenced by state policies, it is implemented at the local level (Erickson, 1995). Planning involves the careful study and analysis of current land use needs and the anticipation of future needs based on population projections. Planners carefully study population projections and suggest the amount of land needed for future development in order to support the increased population (FAO, 1995). However, traditional land use planning may not engage the natural resources and water quality issues in ways that it would be. Land use planning has become an important step to ensure long-term sustainability of natural resources. Land-use planning may be defined as a systematic process for the arrangement and allocation of land resources among period of time and space in accordance with the principles of sustainable land-use (Tu, 2010). Accordingly, the focus of land-use planning is on regulating and adjusting proportions of lands listed in the system of land classification and zoning, as well as resource preservation and protection of the environment (Wang, 2001).

More specifically, land use planning is a unique plan concerned with understanding the connection between human landscape and the ecological and physical processes that directly and indirectly sustain our existence The environmental or natural resource based approach to planning seeks to explore economic growth alternatives that are socially and environmentally sustainable (Yin et. al., 2005). Currently, natural resource based land use planning is one of the most powerful tools available to communities (Wang, 2001). The goal of planning is to shape the built environment for the benefit of society to meet the needs of all people and accommodate a growing economy, while at the same time conserving natural resources and protecting the environment. This goal would potentially include a community's high quality of life, a rural sense of place, and natural resource protection. By combining community input and values with proper land use planning, and responding effectively to the needs and demands of a growing state such as, the quality of life and rural character people want can be sustained for years to come (Xian et al., 2007).

Government performs land use planning to organize and regulate the use of land so that there is space for people to occupy, for agricultural production and to utilize resources above and below the surface, while protecting the environment. Land use plans designate specific areas for certain functions. Land use planning is a cross-sectoral and integrative decision-making process that facilitates the allocation of land to the uses that give the greatest sustainable benefit. This means that all matters relating to land use have to be taken into consideration and agreement must be reached on how best to use the land to avoid failures and conflicts when allocating land to specific functions (FAO/UNEP, 1999).

Decisions related to land use are influenced by socio-economic and environmental conditions, as well as by anticipated demographic developments in and around a natural land unit. This makes it impossible to delegate land-related decisions to only one organization addressing land issues, thereby requiring a broad, integrated and inter-disciplinary approach. Land-related interventions need careful, holistic and sector-overarching coordination; a wide range of expertise must be accessed through the integration of all stakeholders to avoid conflicts, land degradation, and setbacks in the development (Sandovala et al., 2010).

It is difficult to integrate all these stakeholder groups in the process of preparing a land use plan. The concepts, strategies, and policies for preparing land use plans have to address the way how stakeholders are integrated in the decision- making process. There are different systems, methods, and instruments available to do so. Ideally, a “bottom-up” approach is applied, which starts with planning at a local level, involving civil society. These “grass-roots plans” are then integrated with higher level plans.

Land and Land use

Land is a delineable area of the earth’s surface. Below and above this surface, it holds many kinds of resources. A variety of minerals are found below or on the surface, and soils in the upper layer, just below the surface, are an essential resource for agricultural production. Water runs on the surface of land in the form of rivers and lakes; plants form forests and other vegetation types on the land surface; animal populations live amongst and depend on these vegetation formations; and finally, people live on the land and alter it to suit their needs. The need of people gives land important functions for livelihood, wealth and power, and can also have symbolic importance (Nambia Institute for Democracy [NID], 2000).

FAO (1993) defined land is an area of the earth's surface, including all elements of the physical and biological environment that influences land use. Land comprises the physical environment including climate, relief, soils, hydrology and vegetation, to the extent that these influence potential for land use (FAO, 1976). Indeed, land is an essential natural resource, both for the survival and prosperity of humanity, and for the maintenance of all terrestrial ecosystems.

With the increase in the human population, most places on earth are now influenced by people who utilize the land and its resources and allocate specific functions to it. These functions do not only relate to production through agricultural uses but also are used for many other purposes: where roads and railroads are built on land it has transport functions; where people build their houses on the land, it serves housing and settlement functions; where the land accommodates factories and offices, it might serve industrial functions; where shops and markets cover the land, it has marketing and supply functions; and where national parks, forests or other areas are protected, land has the function of conserving natural resources.

There are many other functions of land which are required for people to organize their lives (Erickson, 1995). In this regard, one might think of education facilities, health facilities, mining resources under the land, land which is used for disposing of waste or land which is restricted in its use to protect water resources above or below the surface. All these functions have one thing in common: they are difficult to combine, since all require a certain delineable space on the earth's surface. And lands are an immovable and limited resource. Therefore, wherever people live together and this is on most places on earth conflicts arise because of different interests and priorities of people regarding the functions for which land is to be used. Typical conflicts about the use of land are: agricultural use versus conservation; mining versus agriculture; housing and urban uses versus agriculture. Therefore, the challenge is to combine as many functions on a piece of land as possible, without destroying the land and its resources. Such combinations of land functions are considered in land use concepts and land use systems. On the other hand, some functions of land require other functions. For example, agricultural land uses require marketing and transport structures to bring the goods produced on the land to places where people can acquire them. This shows that land uses and land-related decisions have to be looked at from a holistic perspective (FAO/UNEP, 1995).

Land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it (FAO, 1997). It is a series of operations on land, carried out by man, with the intention to obtain products and/or benefits through using land resources. According to Huizing et al., (1995) land use can lead to positive or negative impacts on land cover because land use is the human activities of natural environment. Land use and land management practices have a major impact on natural resources including water, soil, fertility, plants and animals.

Land sustainability

Nowadays, sustainability is one of the important issues in land use system. Sachs (1992) defined five dimensions of sustainability namely, economic, social, spatial, cultural and ecological, which should be taken into consideration while dealing with land use. It is a measure of the extent to which a form of land use is expected to meet the 'pillar' requirements of productivity, security, protection, viability and acceptability into the future. Sustainability is the ability of an agricultural system to meet evolving human needs without destroying and, if possible, by improving the natural resource base on which it depends (USAID, 1988). FAO (1993) briefly defined sustainable land use as perfect balance between production and conservation and commonly used popular definition is use of land which meets the needs of the present while at the same time conserving resources for future generations (WCED, 1987).

FAO (1976) defined land suitability as the fitness of land for a specified kind of use. In general sustainability indicates that there is a relationship between sustainability and suitability, stability, land degradation, and land use. This suitability of land is a function of crop requirements and soil/land characteristics and land suitability refers to use of land on a sustainable basis. It means that land suitability evaluation should take account of the hazards of soil erosion and other types of soil degradation (FAO, 1983). The sustainable land use should have maximum suitability and minimum vulnerability. Land suitability is a component of sustainability evaluation of a land use.

The Planning Process

Ideally, the process of land use planning can be summarized in five major stages: the organizational stage; the analytical stage; the planning stage; the decision-making stage; and the implementation stage (Figure 2). All these stages more or less follow on each other.

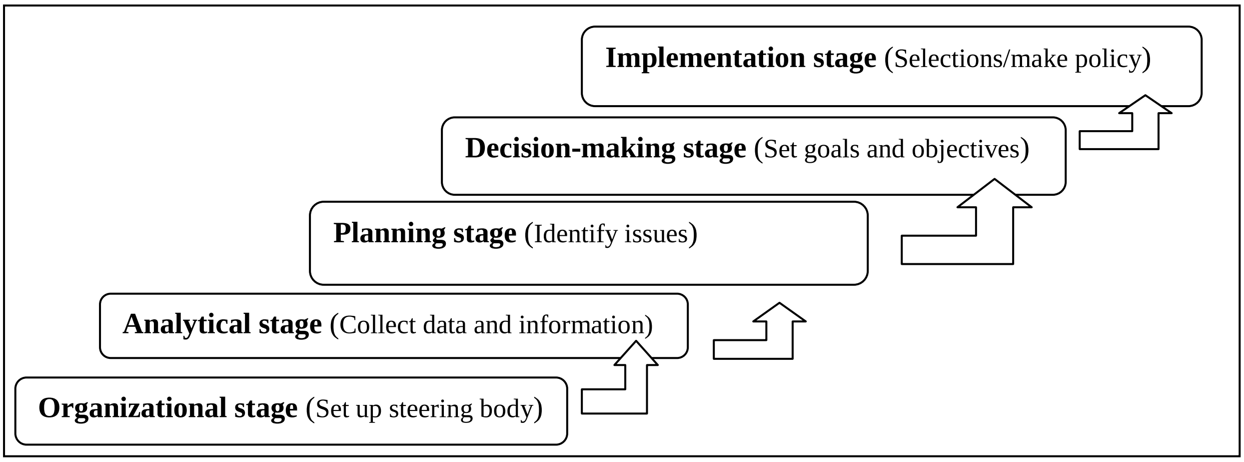


Figure 2. Stages of the land use planning process
Source: FAO (1986)

FAO guidelines for land use planning

The procedure of a relative comprehensive land use planning in “the Guidelines for Land Use Planning” (FAO, 1995) which includes land suitability assessment is illustrated in Figure 3. Each step represents a specific activity, or set of activities, where outputs provide information for subsequent steps.

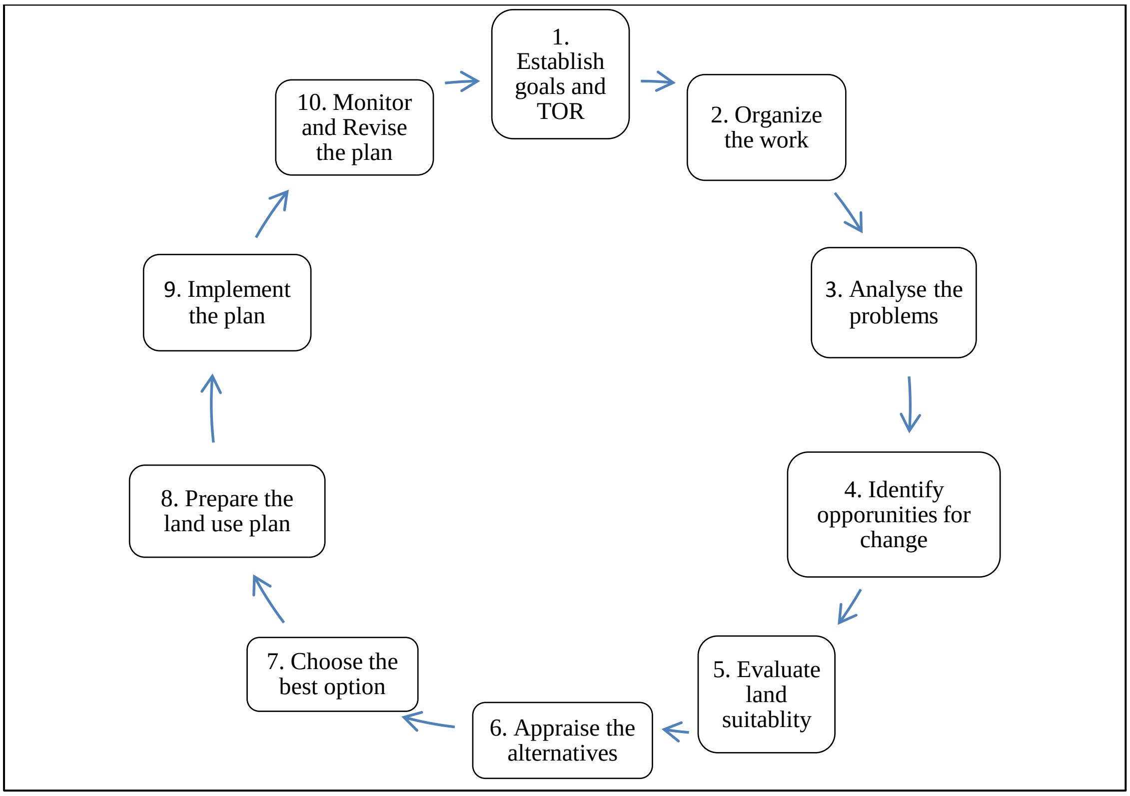


Figure 3. FAO Guidelines for land use planning Source: FAO (1995)

Step 1 to step 4 are the foundation of the land use planning. They include establishing the goals of planning according to the needs of land users and governing and organizing the work plan of the planning group. Then land planners will analyze the existing land use problems and seek a variety of reasonable solutions, ultimately selecting the most promising one based on the consensus of land users, planners and decision-makers. During this process, planners and decision-makers will know about the problems of the planning area and identify the objectives they want to achieve. The fifth step is evaluating land suitability. For this step, the planner will find out which areas of land are best suited for the specified kind of land use. First, the planners need to determine the requirements of a given land use type and conduct surveys to map land units with their physical properties. The land use type is a kind of land use described in terms of its products and management practice (FAO, 1993). The planners may modify the existing land use. Second, planners compare the requirements of the land use type with the properties of the units to arrive at a land suitability classification. Mapping land units and their characteristics, setting limiting values for land use requirements, and matching land use with land are the basis for this procedure. Then, the planners need to map land suitability for each land use type. The sixth step is appraising the alternatives. The evaluation carried out so far has been essentially in terms of physical suitability. In the seventh step, the planner has to summarize the results obtained from the previous steps and the decision-makers have to choose the best land use option that meets the planning goals. Eighth step through the tenth step, the planners will present and implement the plan. The decision makers and the government may introduce regulations and plans to the land users to help implementation of the plan. At the last step, the decision-makers and the planners will see how well the plan is implemented. By this way, the planning process comes to the full circle.

Challenges of land use planning

Land use change is a growing problem confronting policy, planning and decision making at all levels. It links problems and opportunities in urban and metropolitan communities to the larger issues of economic growth and environmental quality (Erickson, 1995). Land use change is the critical connection between economic, housing, policy, jobs, and environment and so on. The frontier expansion and population growth has primarily accelerated land use change in recent centuries. Land resources in some developing countries face pressures from continuing land degradation and increasing numbers of people. Sometimes the conflict between different kinds of land use is inevitable, especially in developing countries, which can further intensify the imbalance between land use and human activities leading to degradation of land resources. Urbanization, defined as urban population proportion of the total population, is growing rapidly and has impacted significantly on spatial urban development, especially on urban land use. Rapid urban population expansion and urban sprawl in the developing world has been discussed well in recent years. As both urban land and rural land are resources in need of effective planning because of their importance in social and economic development, people migrate from rural areas to urban centers seeking more working opportunity and income. Sprawl is a spatial problem which links issues in the central city and the rural landscape. The need for effective land use planning is one of the consequences of the rapid urban population expansion and urban sprawl. In metropolitan areas urban sprawl is also related to negative impacts of poverty and social inequities, while in rural areas it involves the irretrievable loss of farms, rural livelihoods, and open space. Over the last two decades, along with economic growth throughout the world there has been considerable land use change and development in the suburban and rural fringe of many metropolitan areas (FAO, 1993). The trend of farmland loss is particularly evident in rural and suburban communities outside major urban centers. Since social-economic conditions have shown a great change urban and suburban land development is now an emerging issue that needs to be addressed.

Effective land use planning is necessary in order to ensure the orderly growth and development of both urban and rural areas. The process of expansion to the suburban fringe reflects some new environmental and landscape problems. The overall decision-making process must incorporate the entire suite of factors, including transportation, population growth and distribution, economic growth and distribution, location and quality of jobs, location of retail, commercial and residential development, land values which change and development, and changes in the landscape and environment. These factors need to be considered in their current form and consideration should be given to how they may change in the future. The future development of each area should be in accordance with a comprehensive plan for land use prepared for the entire metropolitan region, in order that future generations will not be saddled with an inefficient arrangement of land uses (Kombe, 2005).

Land use change in river basin is an increasingly important issue confronting a range of stakeholders and policy makers at all levels of government. There is a pressing need to use its limited land resources more efficiently and effectively because of its growing population and the urbanization effects associated with globalization processes. The rapid urbanization process has caused an unprecedented rate of urban land expansion. The intensified land use conflict and rapid depletion of agricultural land resources have emerged as a result of the new policy and fast development of land use and economy in many fast growing cities. Many land-related problems have been identified, including agricultural land loss, water pollution, soil erosion, and an increase in the magnitude and frequency of flooding in recent years. In particular, fast urban expansion has triggered the loss of a large amount of agricultural land in many fast developing areas (Kombe, 2005).

Tong, (1990) found that urban development in the watershed caused substantial modification on flood runoff and water quality. Changing land use and land management practices are therefore regarded as one of the main factors in altering the hydrological system, causing changes in runoff (Mander et al., 1998), surface water supply yields, as well as the quality of receiving water. Wang (2001) mentioned that there is significance relationship between the land use patterns with water quality of river and suggested that integrating water quality management and land-use planning is the best way to handle this type of problem. Ngoya and Machiwa (2004) studied on the influence of land use pattern in the Ruvu river watershed on water quality in the river system. They found that forested areas had lower levels of nutrients compared to areas close to human settlements. Agricultural areas also significantly contributed to higher concentration of nutrients concentration in the Ruvu river system. They suggested planned land use management concept should be introduced in catchment area where the rivers are polluted by human activities. Similarly, Ren et al., (2003) did research on the changing pattern of urbanization as well as land use pattern on the water quality of Huangphu River. The study showed that rapid urbanization corresponds with rapid degradation of water quality. It also showed that urban land uses are positively correlated with the decline in water quality.

Integrated land use planning

Based on the experiences of many researchers, academicians, and governments in many countries, modern concepts of land use planning consider the integration of different perspectives, needs and restrictions in the land use planning process. This approach to land use planning is called Integrated Land Use Planning (ILUP). ILUP examines all uses of land in an integrated manner. This is the only way to make the most effective and efficient use of land and natural resources, to link social and economic development with environmental protection, to minimize land-related conflicts and to achieve the objectives of sustainable development (FAO, 1988,1990,1995). The core of the integrated approach is the coordination of sector planning and management activities that relate to the various aspects of land use and land resources (FAO/UNEP, 1999). Land resources are used for a variety of purposes; as these interact and may compete with one another, it is necessary to plan and manage all uses in an integrated manner. The purpose of land use planning therefore is to select and put into practice those land uses that will best meet the needs of the people while safeguarding resources for the future. Land use planning should not take place in isolation from other developmental planning; rather they should be integrated (Namibia Nature Foundation [NID], 2010).

The principles of ILUP are:

- Although ILUP is a uniform process, it is not a standardized one, as it reflects the regional or local situation.

- ILUP aims at sustainability (balancing social, economic and environmental needs considering capacity building).
- ILUP promotes civic engagement (it includes active local participation, is based on local knowledge, is oriented towards consensus building and involves stakeholders in decision making).
- ILUP requires sector integration and interdisciplinary cooperation (horizontal integration).
- ILUP integrates bottom-up aspects with top-down aspects (vertical integration of planning levels).
- ILUP is future-oriented (visionary).
- ILUP relates to spaces and places (spatial orientation),and
- ILUP is implementation-oriented through the collaboration of stakeholders.

The fact is that land use is not static, but is influenced by dynamic processes. A plan is therefore bound to a timeframe defining what is to be achieved by when within the given time frame. For instance, over the period of 10 years, new developments might change the basic assumptions underlying the land use plan. Constant reviews and regular updates have therefore to be considered.

Global concern about food security and quality of life for future generations, and growing awareness of environmental degradation pose penetrating questions to science. The 1992 UNCED conference in Rio de Janeiro led to the recognition that the issue of sustainable land use deserves interdisciplinary attention, recognizing its inherent complexity. Following up on Agenda 21 Chapter 10, i.e. the “Program of Action for Sustainable Development”, the FAO suggested an “Integrated approach to the planning and management of land resources.” (FAO, 1994) states the following “The world as a whole has experienced a doubling of its human population over the past half century. The cost to the planet has been high, in terms of destruction of the resource base, degradation of the environment, and effect on global systems.” Decision-making about the use of land resources depends on the availability of the necessary information on physical factors such as climate, soil, water, and on present land use, social factors, and economic factors” (Somalia Water Land Information Management [SWALIM], 2009).

Although many researchers have paid particular attention to the effect of land use on water quality, a water-quality component often is missing in land-use plans and land-use planning. This could be due to the fact that water-quality management and land-use planning often are administrated by different agencies that do not coordinate constantly. Most planning agencies and local authorities do not have resources to collect extensive land use and water quality data in developing plans and water-quality management agencies traditionally address existing water-quality problems rather than preventing them (Wang, 2001).Therefore, it is essential to protect local water resources by thinking on a watershed planning level. Watershed-based planning is important because it involves decisions on the amount and location of development and impervious cover, as well as choices about appropriate land use management techniques.

The impact of urban land uses on river water quality demonstrated that the known land-water relationship is significant enough for planners and decision-makers to pay proper attention to water-quality issues in evaluating plans and facilitating collaborations. Achieving the sustainable management of water and land resources could be a major consideration in exploring planning alternatives within a watershed. Many studies demonstrate several evidences that call for integration of water-quality management and land-use planning to aim at water uses in a manner that will maximize the socio-economic benefits to the society without jeopardizing the balance of the resource-related ecosystems. The integration of water-quality management and land-use planning can promote protecting the biotic quality and habitat health and preventing pollution, which serves the purpose of protecting water quality and maintaining ecologically and economically healthy land development. This linkage suggests that the goal of protecting water quality through land-use planning can and should be achieved through habitat protection. Maintaining a healthy habitat can help to improve water quality and promote biodiversity and preserve landscape features of the watershed. As water quality and land-use data become more accessible, planners and policy-makers at different levels should bring stakeholders together to substantially increase the health of the environment by identifying sources of the problems, understanding the relationship between the sources and consequences, and searching for solutions to these problems (Wang, 2001).

Integrated land-use planning seeks to balance economic, social and cultural opportunities in a specific area with the need to maintain and enhance the health of the area’s water system. It is a process whereby all interested parties, large and small, come together to make decisions about how the land and its resources should be used and managed, and to coordinate their activities in a sustainable fashion. It holds that maintaining the integrity of the ecosystem is the primary consideration. Integrated land-use planning may also prove valuable in some areas that have already been allocated, as these development rights may have to be reconciled with important emerging demands such as expanding cities, aboriginal land claims and conservation. While integrated land-use planning is an evolving concept that is being implemented to varying degrees across the globe, it already has success stories (Sandovala et al., 2010).

Evaluation of land use

Land use planning is a tool to help policy makers, decision makers, and land users solve current land use problems and to achieve highest possible options for future land use. Land evaluation is one of the main components of land-use planning (FAO, 1986). The evaluation of land depends on interdisciplinary activities that rely on large amounts of information from different sources. But, land evaluation can be done physically and economically. Physical land evaluation is based on physical factors whereas economic land evaluation is based on the economic measures of benefits of specific land utilization. Therefore, land evaluation may be conducted in either physical or economic terms. However, a lot of land use decisions are made on the basis of socio-economic aspects, hence the principal objective of land evaluation is to collect the optimum land use for each type of land, taking into account both physical and socio-economic considerations and the conservation of environmental resources for future use (Rossiter, 2001). Both physical and socio-economic analyses provide the foundation for land evaluation and ultimately for land use planning (FAO, 1984, 1991, 1993).

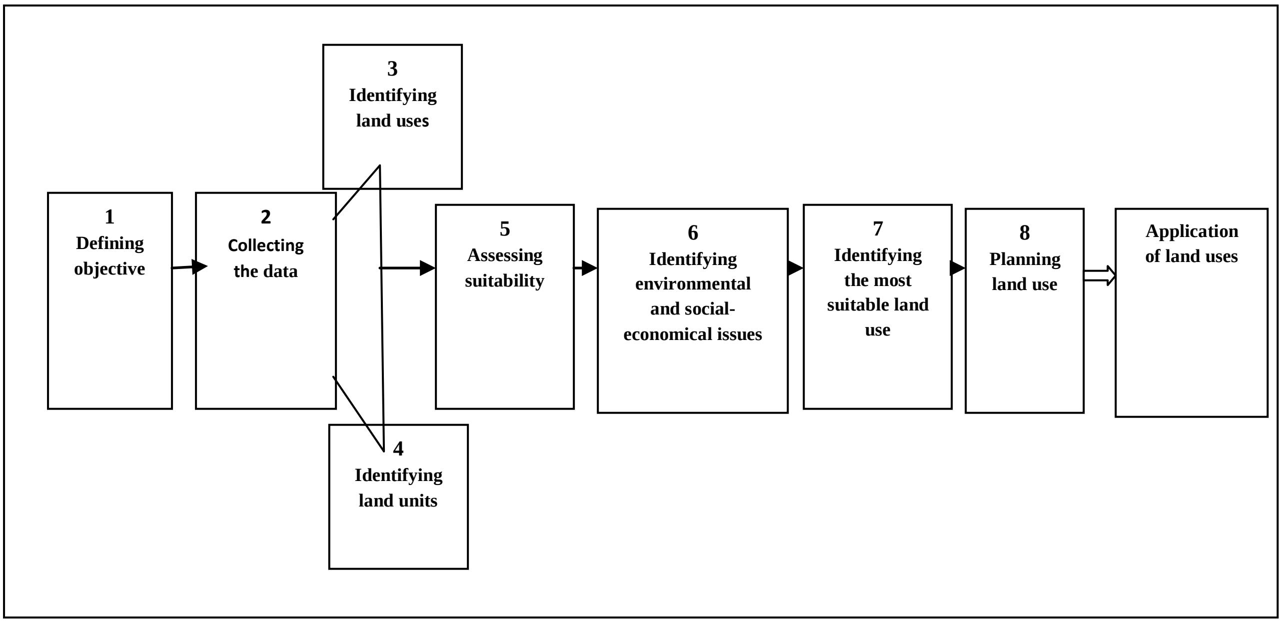


Figure 4. Steps of land evaluation and land use planning
Source: FAO (1986)

The principles and general approach adopted for land evaluation start with the publication of the FAO Framework for Land Evaluation (1976) and has proved to be one of the most durable and widely used FAO methodologies in evaluation of land resources. Based on the objectives of the evaluation, the framework uniformly defines concepts related to land evaluation such as land, land mapping unit, major kinds of land use, land utilization types, multiple and compound land use, land characteristics, land qualities, diagnostic criteria, land use requirements, imitations, land suitability, land suitability order, class, subclass, unit and potential suitability classification. The main objective of the land evaluation is the prediction of the inherent capacity of a land unit to support a specific land use for a long period of time without deterioration, in order to minimize the socio-economic and environmental costs (FAO, 2003).

Land suitability

Land suitability is a part of land use planning methodology and defines possible options for the future land use for decision makers. FAO (1985) analyzed land suitability mainly focusing on the land quality. Land quality is an attribute of land which acts in a distinct manner in its influence on the suitability of the land for a specific kind of use. Examples of land qualities widely applicable for land use suitability are temperature regime, moisture availability, soil drainage, rooting conditions etc. (FAO, 1984). Usually land quality cannot be measured or estimated in a routine survey, which must be inferred from a set of diagnostic land characteristics. Most land qualities are determined the interaction of land characteristics, which are measurable attributes of the land.

Land suitability analysis is an interdisciplinary approach which includes information from different domains like soil science, crop science, meteorology, social science, economics and management. In general, land suitability analysis indicates the influences of physical issues in relation with social-economic, infrastructure, environmental issues. The results are intended to be used for land resource related decision making, both strategic land use planning by policy/planning institutions such as extension agencies, and specific local land allocation by the direct land users, that is, the farmers. Generally, land suitability is the fitness of a given type of land for a defined use and assessment of land suitability is made by comparison between land use and land quality, coupled with analysis in environmental, economic and social terms (FAO, 1984). Suitability is a measure of how well the characteristics of a land match the requirements of sustainable development. The preparation of sustainable development plan requires consideration of all components of the economic, social and environment. Land suitability evaluation can also be defined as the assessment or prediction of land quality for a specific use, in terms of its productivity, degradation hazards and management requirements (Alejandro & Jorge, 2000; Allen et al., 1995; Collins et al., 2001).

Processes of land suitability analysis (Figure 4)

- Defining objectives
- Collecting the data
- Identifying land uses and their units
- Identifying environmental and socio-economic issues
- Assessing land suitability

Defining of objectives is an important step in the suitability analysis. It helps investigators to set off the right direction, with a good chance of providing all the advice that the planners will need. After setting objectives, the next step is to collect data. To manage the data collection, it should be focused on maximum utilization of existing data adjusting new technology and concentrating on suitability analysis. For the case of identifying relevant types of land use, reliable knowledge of land characteristics, and of the way these differ from place to place, is essential to good land evaluation. For this case, the investigators should carry out surveys to establish needs and wishes of the local land users and needs of the community as a whole and should rank objectives in order of priority. For the case of identifying environmental and socio-economic issues; this can be done after having discussion with local people and experts in these areas.

As mentioned above, land suitability is the fitness of a given type of land for a specified kind of land use. The process of land suitability classification is the appraisal and grouping of specific land in terms of their suitability for defined uses (FAO, 1984).

Land Suitability Orders: Reflecting kinds of suitability, land suitability orders indicate whether given types of land are suitable or not suitable; for the land utilization type concerned. There are two orders represented by the symbols S and N. The areas that are not assessed are allocated to an extra class “NR” meaning not relevant. Land suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration.

Land Suitability Classes: Land suitability classes reflect the degrees of suitability. The classes are numbered consecutively, by Arabic numbers, in sequence of decreasing degrees of suitability within the order, three classes are normally recognized: Highly suitable, moderately suitable and marginally suitable, indicated by symbols S1, S2 and S3 respectively.

S1 (Highly suitable): Land having no significant limitations to sustained application of a given land utilization type, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.

S2 (Moderately suitable): Land having limitations which in aggregate are moderately severe for a sustained application of a given land utilization type. The limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use will be appreciably inferior to that expected on class S1 land.

S3 (Marginally suitable): Land having limitations which in aggregate are severe for sustained application of a given land utilization type and will so reduce productivity or benefits, or increase required inputs, that this expenditure will only be marginally justified.

N1 (Currently not suitable): Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost. The limitations are so severe as to preclude successful sustained application of the given land utilization type.

N2 (Permanently not suitable): Land having limitations which appear as severe as to preclude any possibilities of successful sustained application of a given land utilization type.

Land Suitability sub-classes: Subclasses reflect kinds of limitations or required improvements measures within classes.

Land Suitability Units: This indicates the differences in required management within subclasses.

Multi criteria decision making (MCDM)

Assessment of land use suitability is the essential part of land use evaluation and land use planning. But, determining suitable land for a particular use is a complex process involving multiple decisions that may relate to biophysical, socio-economic and institutional/organizational aspects. Therefore, for land use suitability analysis, many criteria should be integrated and evaluated with respect to many alternative land use types.

The main purpose of the Multi-criteria evaluation techniques is to investigate a number of alternatives in the light of multiple criteria and conflicting objectives. Multi-criteria evaluation for land use issues is not a new concept, however multi-criteria evaluation based on the same principle, but implementing explicitly reasoned decision rules to enable the combination of many criteria into a single index of suitability is the new concept. Multi-criteria evaluation is a transparent way of systematically collecting and processing objective information, and expressing and communicating subjective judgments concerning choice from a set of alternatives affecting several stakeholders. Such systematic, rational and transparent judgments most probably lead to more effective and efficient decisions by individuals or groups of decision makers (Deng, 1999; Carver, 1991).

Analytical hierarchical process (AHP)

MCDM method has to deal with heterogeneous criteria that are both qualitative and quantitative in nature. With these criteria, some criteria are more important than others. For this case, ranking and rating are generally used on the basis of personal judgment method and this method is mostly criticized for not reflecting the decision makers' views clearly and also for not having any rationale behind the approach. To overcome this problem, Saaty has developed Analytical hierarchical process (AHP) and nowadays, it is widely used in land use suitability analysis (Saaty 1980; Saaty & Vargas, 1988). The AHP is based on three principles: i) decomposition of the overall goal, ii) comparative judgment of the criteria, and iii) synthesis of the priorities. So, the first step of AHP technique begins with the structuring of the criteria and sub-criteria required for the land suitability and set them in a hierarchical form. The overall goal of the research is suitability evaluation which occupies the top most level in the hierarchy. The next level consists of the main criteria set out to support the goal, and sub-criteria of the criteria occupy position in the next hierarchical level. At the bottom level there are the alternatives to be evaluated. Such structure allows the incorporation and accommodation of both qualitative and quantitative criteria for assessing land suitability. The hierarchical structure is illustrated in figure below:

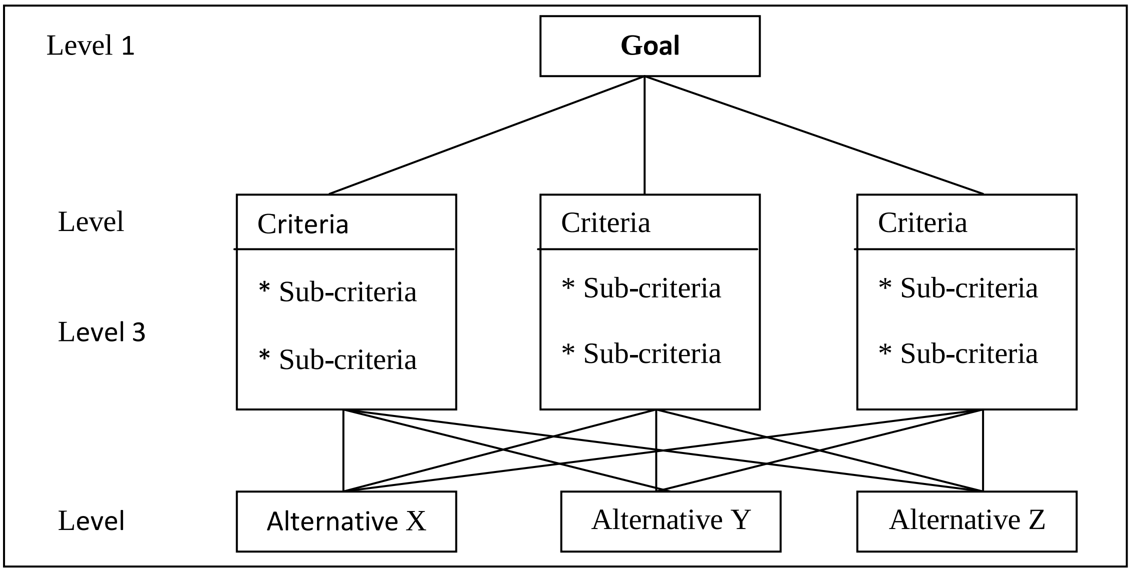


Figure 5. AHP: Hierarchical structure

Source: Saaty (1980)

AHP offers some advantages over the classical site suitability analysis techniques. First, it provides a structural approach to measuring suitability by “decomposing” the suitability analysis problem into hierarchical units and levels. This allows a systematic and more in-depth analysis of the factors which may be better understood when it is deconstructed into their lower and more specific forms or indicators. Second, AHP relies less on the completeness of the data set, and more on “expert” opinions or observations about the different factors and their perceived effects on land suitability. Third, the approach is more transparent and hence more likely to be accepted especially when the suitability analysis ultimately serves as a basis for land allocation. Fourth, AHP allows for the participation of both experts and stakeholders in providing the suitability measure of a land relative to a proposed land use. Such framework allows the incorporation and accommodation of both qualitative and quantitative criteria for land suitability assessment analysis.

In multi criteria decision making process, giving values or weight to different criteria is very complicated and challenging. To overcome this problem, Saaty (1980) has adjusted pair wise comparison method with AHP. In this technique, the decision maker will perform simple pair-wise comparison (comparing two elements at a time). The values of the pair-wise comparison are determined according to the scale introduced by Saaty (1980). The available values for the comparison are the member of the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9}, 9 representing absolutely importance and 1/9 representing absolute no importance.

Table 4
Fundamental scale used in pairwise comparison

Qualitative Definition	Explanation	Intensity of importance
Equal importance	Two activities affect equally to the objective	1
Weak		2
Moderate importance	Experience and judgment slightly favor one activity over another	3
Moderate plus		4
Strong importance	Experience and judgment strongly favor one activity over another	5
Strong plus		6
Very strong	An activity is favored very strongly over another and dominance is demonstrated in practice	7
Very, very strong		8
Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation	9

Source: Saaty (1980)

Even though, Saaty’s judgment matrices have received a relatively wide acceptance as being an effective way for extracting qualitative information for real world MCDM problems, there is a problem of handling large number of criteria and sub-criteria. To adjust this problem, Saaty’s method makes use of eigenvalue theory (a modified least squares problem in AHP) and entails the construction of a decision matrix by using the relative importance of the alternatives in terms of each criterion. With regards to internal uncertainty, an index of some sort was required to evaluate the reasonable level of consistency in the pair-wise comparisons. Saaty (1980) developed what he calls the consistency ratio (CR), which involves the maximum right eigenvalue. In essence, the CR is designed in such a way that if CR < 0.10, the ratio indicates an acceptable level of consistency; if however, CR ≥ 0.10, the values of the ratio are indicative of inconsistent judgments and revision is required.

The formula of Consistency Ratio (CR) got from the Consistency Index (CI) is as follows:

$$\mathrm{CI} = {}^{(\lambda\mathrm{max} - \mathrm{n})}\!\big/_{(\mathrm{n} - 1)}$$

$$\mathrm{CR} = {}^{\mathrm{CI}}\!/_{\mathrm{RI}}$$

Where:
λmax: The maximum eigen value
CI : Consistency Index
CR : Consistency Ratio
RI : Random Index
n: The numbers of criteria or sub-criteria in each pairwise comparison matrix

Random Index (RI) says that the average of consistency of comparative matrix in pairs is 1-10, obtained from the experiment of Oak Ridge

National Laboratory and Wharton School. The bigger the matrix is, the higher the inconsistency level will be. Matrix Random Index shown in table below.

Table 5

Average random consistency index (RI)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The requirements are:

If CR ≤ 10%, means matrix is consistent and AHP can be continued

If CR > 10%, assessment and revision is required because matrix is not consistent

Geographic Information Systems (GIS)

A geographic information system (GIS) is a computer based tool for mapping and analyzing geographic phenomenon that exists and events that occur on earth (Baniya, 2008). In general, a GIS provides facilities for data capture, data management, data manipulation and analysis and the presentation of results in both graphic and report form, with a particular emphasis upon preserving and utilizing inherent characteristics of spatial data. The ability to incorporate, manage and analyze spatial data, and answer spatial questions is the distinctive characteristic of GIS. It has also the ability to integrate a variety of geographic technologies like Global Positioning System (GPS) and Remote Sensing (Basnyat et al., 2000). By these utilities, GIS can support spatial decision making process in effective way (Bandyopadhyay et al., 2009).

Generally, GIS integrates five key components, namely Hardware, Software, Data, People and Methods to operate the system. Hardware is the computer system on which a GIS operates and Software provides the function and tools needed to store, analyze, and display geographic information. Data is the important component of a GIS. Basically, GIS utilizes two types of data: spatial data which describes the absolute and relative location of Geographic features and attribute data which describes the characteristics of the spatial features and these characteristics can be quantitative and/or qualitative in nature. Traditionally spatial data has been stored and presented in the form of a map. Three basic types of spatial data models have evolved for storing geographic data digitally. These are referred to as Vector, Raster and Image. People are an important part of GIS because it is the people who manage the system and develop plans for applying it to real world problems.

Four main functions of GIS

Data Input: Data input allows the user to capture, collect and transform spatial and thematic data into digital form. Digital data are collected from many sources such as aerial photographs, satellite images, field samples, and scanning or digitization of hard copy maps.

Data management (storage and retrieval): One of the key elements of this work is the building of the database capable for the storage, retrieval, and sharing of the data in an easy and efficient way. The data storage and retrieval subsystem organizes the data with spatial attributes which permits it to be quickly retrieved by the user for analysis and permits rapid and accurate updates to be made to the database. The main objective of this phase is making data ready for various types of classification for different applications mostly for land suitability evaluation.

Data manipulation and analysis: The data manipulation and analysis subsystem allows the user to define and execute spatial attributes to generate the derived information. Analysis is a process for looking at geographic patterns of data and the relationship between features; and this can be as simple as making a map or as complex as involving models that mimic the real world by combining many data layers. Manipulation involves transformation (i.e., from raster to vector data structure), generalization, overlay, and interpolation procedures.

Data output: The data output subsystem allows the user to generate graphic displays normally maps and tabular reports representing derived information products. So, output is the final stage of the presentation of the result to the end users and decision makers. The results of GIS can be reported as a map, values in a table, or as a chart.

GIS provides a powerful set of tools for data visualization, data analysis and evaluation of scenarios. It is an integrating technology that allows, encourages and expects users to bring data together from many different sources through the unifying medium of geography. GIS can be used in concrete applications ranging from resource assessment to land evaluation and land use planning. One major part of GIS is the ability to overlay various layers of spatially referenced data, allowing the user to determine graphically and analytically, how structures and objects, interact with each other.

Integrating GIS, AHP and MCDM for land use suitability analysis

The general objective of multi criteria decision making (MCDM) is to assist the decision maker in selecting the ‘best’ alternative from a number of feasible alternatives under the presence of multiple choice criteria and diverse criterion priorities. But, managing multi-criterion choice in decision making is major challenge faced by individual, public, and private cooperation. To handle this problem, Analytical Hierarchy Process (AHP) is a widely used method in multi-criteria decision making and was introduced by Saaty (1980). AHP is a proven, effective means of dealing with complex decision making and can assist with identifying and weighing selection criteria, analyzing the data collected for the criteria, and expediting the decision-making process (Saaty, 2000). By making pair-wise comparisons at each level of the hierarchy, participants can develop relative weights, called priorities, to differentiate the importance of the criteria.

Land suitability analysis is inherently a spatial multi-criteria decision making process (Store & Kangas, 2001). Determining suitable land for a particular use is a complex process involving multiple decisions that may relate to many biophysical factors. In practice, land use suitability cannot solely be done only from biophysical resources information. The other socio-economic factors like transportation network, local economy, education, demographic features etc. should be included for decision making process. So, the AHP is a practical and effective method for solving spatial multi-criteria decision problems which uses hierarchical structures to represent a problem and then develop priorities for alternatives based on the judgment of the user (Saaty, 1980).

In suitability based land use planning, GIS is very effective (Florent et al., 2001). GIS helps the user to determine what locations are most/least suitable for specific purpose (Lo & Yeng, 2002). In this way, the results of GIS analysis can provide support for decision making. It also enables to create and modify any land suitability analysis that makes the best use of available data (Sieber, 2006; Prakash, 2003; Raghunath, 2006). In spatial decision making process, development of specific criteria is crucial to locate optimally suitable geographic areas for a specific land use. Criteria can be of two kinds: factors and constraints. Constraints are Boolean criteria that constraint (i.e. limit) the analysis to a particular geographic regions. In contract, factors are criteria that define some degree of suitability for all geographic regions. The ultimate aim of GIS is to provide support for spatial decision making process (Store & Kangas, 2001).

Scenario analysis in land use planning

High quality land use planning provides a clear and convincing picture of the future, which strengthens the plan's influence in the land planning arena. Even land use planning has significance importance for policy maker; it is surprising that it is not routinely evaluated against accepted plan quality standards (Berke & Godschalk, 2009). Highly evaluated land use plans have wide-ranging powers to influence environmental justice, disaster resistance, transportation efficiency, infrastructure costs and many other important aspects of community life (Berke & Godschalk, 2009; Knaap et al., 2001). If planning has to achieve its full strength, it should reflect its objective and application values. Only systematic evaluation enables us to identify its specific strength and weakness, to judge whether its overall quality is good, and to provide a basis for ensuring that it reach a desirable standard. Planning evaluation is itself a learning process that yields important planning lessons and guidelines (Berke & Godschalk, 2009).

For evaluation land use planning, many researchers or policy makers have been using various criteria which might dependent on the goals and objectives of the planning process. Baer (1997) has adapted the socio-economic and legal framework to evaluate the planning map. Evaluation of planning is emerging as a valuable tool for systematic analysis of the goodness of plans. Many studies have done of evaluation of land use planning on issues like natural hazards, sustainable development, human rights, coastal area management and housing affordability (Burby et al., 1997; Berke et al., 1997; Godschalk et al.,1999; Brody,2003; Edward & Haines,2007).

Scenario analysis methods were used in various fields (Foran & Wardle, 1995; Mohren, 2003; Hoyland, 2001). In land use planning aspect, scenario analysis method is frequently used. In land use planning perspective, scenario based decision making tool is very supportive and it gives idea to select the best strategy or policy for management decision making. A scenario describes a possible future state of an organization's environment, and considers possible developments of relevant interdependent factors in this environment. The method is particularly useful for strategic planning when the future is perceived as bound by a high degree of uncertainty (Kepner et al., 2004). For example, Baker et al. (2004) did scenario analysis by developing three types of land use alternative in Willamette River Basin, Oregon and these scenarios have evaluated on river condition, water availability & use, stream condition and terrestrial wildlife. Kepner et al. (2004) developed three types of scenario maps of San Pedro River Basin by integrating hydrologic modeling with a scenario analysis framework to evaluate plausible future forecasts and understand the potential impact of landscape change on water system. In scenario analysis, Water Evaluation and Planning Tool (WEAP) has been using by integrating water availability, water demand, water quality and water use efficiency. For the case of decision making on the base of scenario analysis, Pikounis et al. (2003) has investigated the hydrological effects of specific land use changes in a catchment of the river Pinios through the application of the Soil and Water Assessment Tool (SWAT) and developed three types of land use scenarios as i) expansion of agriculture land, ii) complete deforestation of sub-basin level and iii) expansion of urban areas in sub-basin level. Similarly, Kepner et al. (2008) did scenario analysis to assess future landscape change on watershed condition in the Pacific Northeast (USA) by utilizing GIS and SWAT model. For this study, they studied potential impact of three future scenario of 2050 (conservation, plan trend and development) on hydrologic condition of the basin. It was found that the conservation and plan trend alternatives have the least negative impacts to the surface water hydrology.

The concept of scenario analysis can be used to the changing pattern of land use on sustainable development issue. For example, Hu & Lian (2009) investigated the changes of the landscape pattern and the changes of the ecological sustainability in five land use scenario which were proposed based on land use analysis, land suitability evaluation, planning and peasant's demand in Ansai Country, China. They found that the scenario having concentrating cropland to loessial soil with slope $<15^0$ and converting the rest of the land to orchards, woodlands, shrub lands, grassland was a good choice from ecological sustainability point of view. Theobald and Hobbs (2002) developed multiple scenarios and also did scenario analysis for how planning alternatives could affect critical habitat of the region. In this study, scenario analysis concept was also used to evaluate the land use planning map of U-tapao river basin on water quality framework.

CHAPTER 3

STUDY AREA

Geographical location

U-tapao River Basin (URB) is one of the parts of the Songkhla Lake Basin, Thailand. Sonkhla Lake is the largest lake (lagoon) in Thailand. The basin has an area 8,729 km^2 including 1017 km^2 of main lake water body, and extents into three provinces (Songkhla, Phatthalung, and Nakon Si Thammarat) (Cheson & Lim, 2008). URB is about 60 km long from north to south, and 40 km wide from west to east, and total coverage is about 2,305 km^2. The longitude and latitude of basin is 100º 10’ through 100º 37’ E and 6º 28’ through 7º 10’ N respectively. With the Universal Transverse Mercator, it lies in the zone 47 N. The north coordinate is PH 656792 and the south is PH677714. The west is in NJ 613770 and the east is PH 680773.

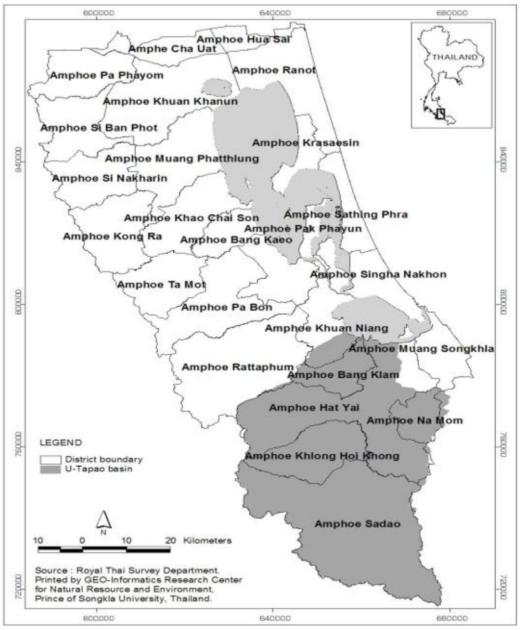


Figure 6. U-tapao river basin and Songkhla Lake basin, Thailand (Source: GEO-Informatics Research Center for Natural Resource and Environment (GEO-INRCNRE).

The U-tapao river is one of the most important rivers of the Basin and the length of river is 68 km and the average depth 3-8 m (Sirtnawin & Sompongchaiyakul, 2005) and the average width of river is 2.45 m (1.5-90 m). The river originates from Sankalakiri and Bantad Mountains and flows from south to north through communities, industries and agricultural areas (Musikavong & Wattanachira, 2010; Sirtnawin & Sompongchaiyakul, 2005) before emptying into the outer part of Songkhla Lake. The discharge ranges from less than 6 m^3/s in the dry season to more than 90 m^3/s in the wet season (Sirtnawin & Sompongchaiyakul, 2005; Musikavong & Wattanachira, 2010). There are two reservoirs namely Sadao Reservoir and Khlonglha Reservoir located in the upstream location of the river. Sadao Reservoir has the capacity approximately of 52 million cubic meters, while Klongla Reservoir has the capacity approximately of 30 million cubic meters. The area covers the reservoir for amphur Hadyai, Sadao, Rattapoom, Kuanniang, Namom, Bangklam, and Klonghoikong.

Political boundary

The whole area of U-tapao river basin (URB) lies in Songkhla province. The area of the province is 7,394 km^2 and the population of density of province is about 179.2 per square kilometer and it is sub-divided into 16 districts or Amphoe (Mueang Sonkhla, Sathing Phra, Chana, Na Thawi, Thepha, Saba Yoi, Ranot, Khrasse Sin, Rathaphum, Sadao, Hatyai, Na Mom, Khuang Niang, Bang Klam, Singhanaklon and Klong Hoi Khong) and it is further subdivided into 127 sub districts (Tambon) and 987 villages (Muban). Out of 16 districts, 7 districts are located in U-tapao River Basin (Table 6).

Table 6

Area of 7 districts of URB

SN	District(Amphoe)	Area (km^2)	Sub-districts	Villages
1	Hatyai	704.56	12	82
2	Klong Hoi Khog	290.16	4	32
3	Rathaphum	12.96	1	
4	Sadao	1028.99	9	66
5	Na Mom	143.90	4	29
6	Bang Klam	142.10	4	36
7	Khuan Niang	59.88	1	7

Source: *GEO-INRCNRE*

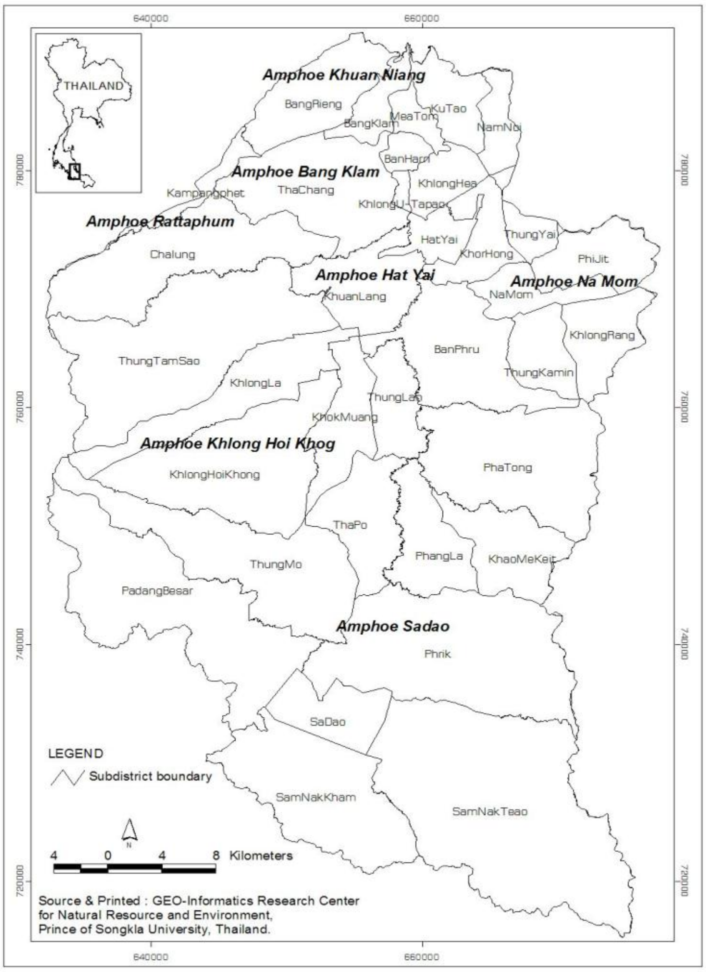


Figure 7. Political boundary map of U-tapao River Basin (Source: GEO-INRCNRE)

Sub-watersheds

The basin is divided into 10 watersheds and the area and land use distribution is given in Table 7 below.

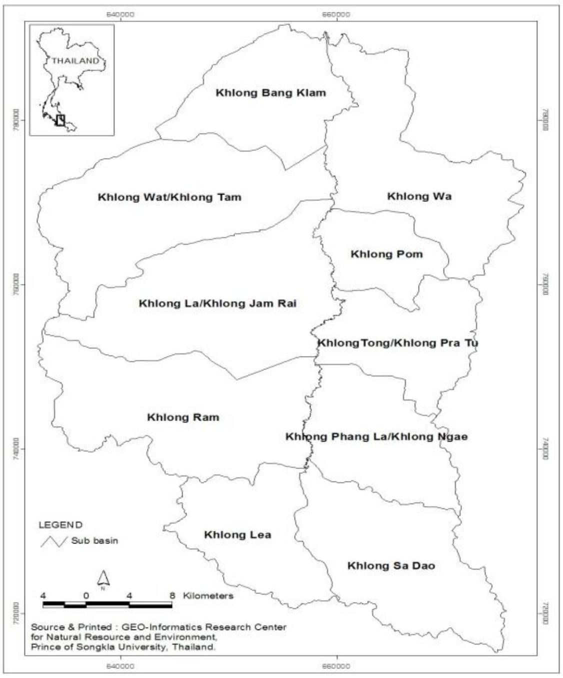


Figure 8. Ten watersheds of U-tapao River Basin (Source: GEO- INRCNRE)

Table 7
Ten watersheds of URB, area and land use distribution in percentage

Watersheds		Area(km^2)	Land use distribution (in %) in 2000			
			Agriculture	Forest	Urban	Water body
WS-I	Klong Bang Klam	144.92	78.64	11.18	2.15	8.03
WS-II	Khlong Wa	257.65	67.59	3.75	13.82	14.84
WS-III	Khlong Wat/Khlong Tam	338.68	68.13	25.86	3.55	2.46
WS-IV	Klong Pom	104.99	84.68	3.18	7.41	4.73
WS-V	Khlong La/Khlong Jam Rai	350.26	78.59	14.57	2.77	4.07
WS-VI	Klong Tong/Khlong Pra Tu	164.29	93.32	4.29	2.26	0.13
WS-VII	Khlong Ram	326.59	84.71	13.91	1.01	0.37
WS-VIII	Khlong Phang La/Khlong Ngae	184.91	90.99	5.89	1.67	1.45
WS-IX	Khlong Lea	172.32	96.72	0.34	2.68	0.27
WS-X	Khlong Sa Dao	260.39	76.83	21.69	0.57	0.91

Climate

Basin has a tropical climate (Meteorological Department, 1994) and is governed by two monsoons; the southwest monsoon causing rainfall during May to September and the northeast monsoon causing rainfall during October to January. Therefore, the wet season starts from May to January, under the influence of the southwest monsoon from May to September and the northeast monsoon from October to January. The average annual temperature of the basin is around 28 ^{0}C and generally, the highest temperature is observed during March through April whereas the lowest temperature is observed during November through January (Figure 9). There is not so much seasonal difference of air temperature in the basin, the average temperature of wet season is 27.17 ^{0}C and that of dry season is 28.46 ^{0}C.

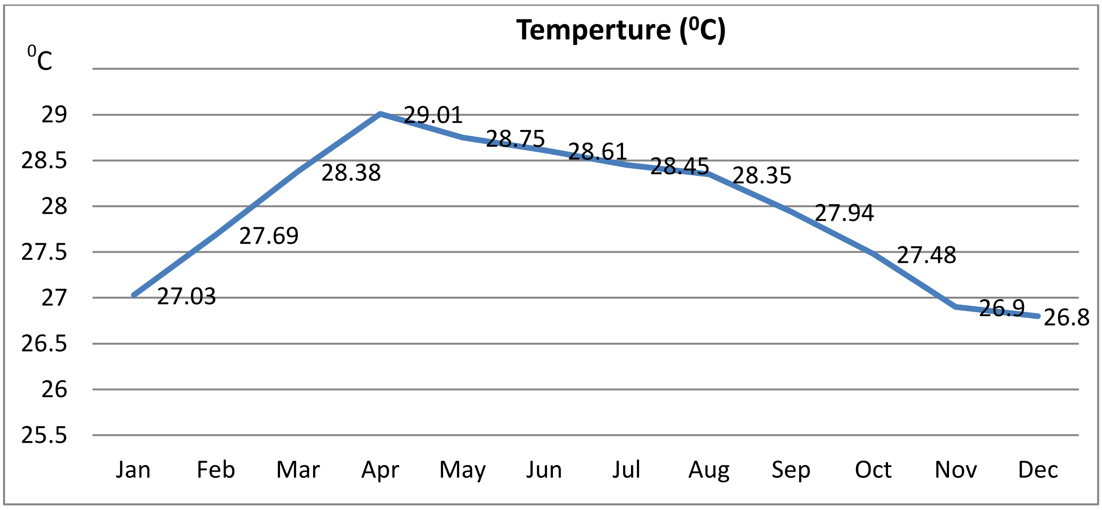


Figure 9. Average monthly air temperature of U-tapao river basin, Thailand
Source: Southern Metrological Centre, Hatyai

During rainfall, the heaviest rainfalls usually occur during the northeast monsoon period, with a major peak in on October–December (Figure 10). The average rainfall in the basin is approximately 2,216 mm per annum varying between

1,600 and 2,400 mm. About 60% of the annual rainfall occurs over a short period between October and December (Panapitukkul et al., 2005). There is a significant seasonal rainfall in the basin, the average rainfall in wet season is 1,782.48 mm whereas in dry season is 433.64 mm (Southern Metrological Department, Hatyai, Thailand).

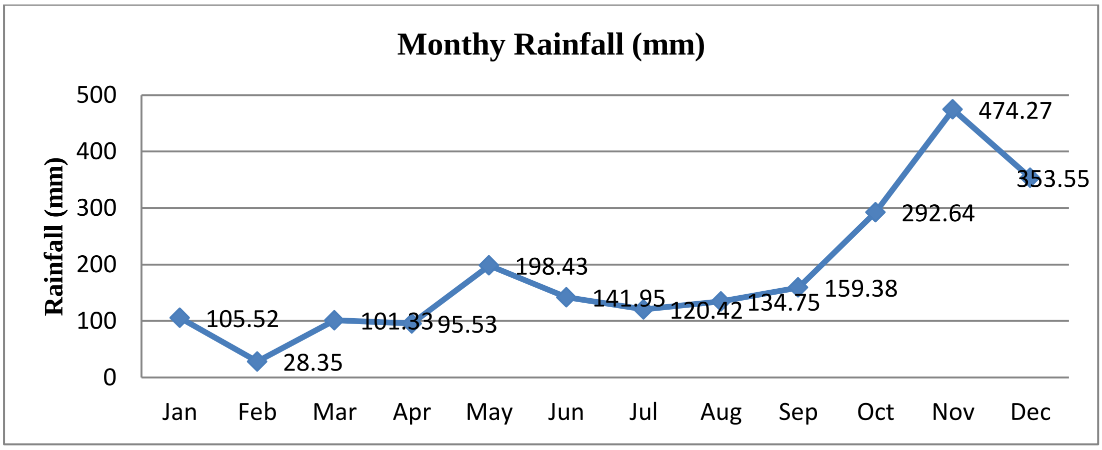


Figure 10. Average monthly rainfall of U-tapao River Basin, Thailand
Source: Southern Metrological centre, Hatyai

The average humidity level of the basin is about 77.96% and the highest values are observed during October through December and the lowest values are observed around January through March (Figure 11). There is a slight difference on mean humidity level on the basin, the average humidity in wet season is 78.99% and dry season is 75.89%. The average wind speed on the basin is around 2.82 km/hr and the highest peak period is during January and lowest is during May (Figure 12). There is a slight difference on mean values of wind speed, the average wind speed in wet season is 2.72 km/hr and in dry season is 3.03 km/hr.

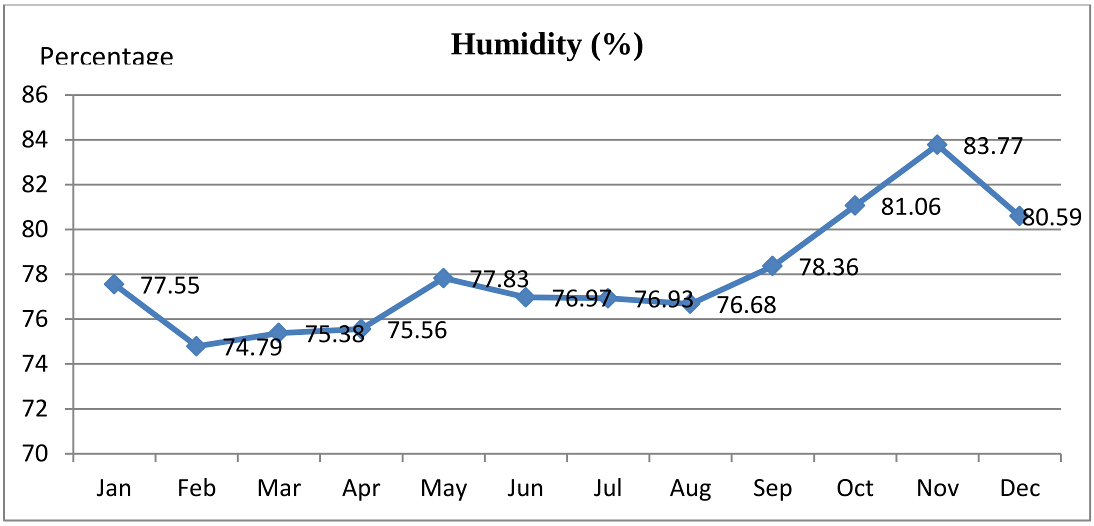


Figure 11. Average monthly humidity of U-tapao River Basin, Thailand
Source: Southern Metrological Centre, Hatyai

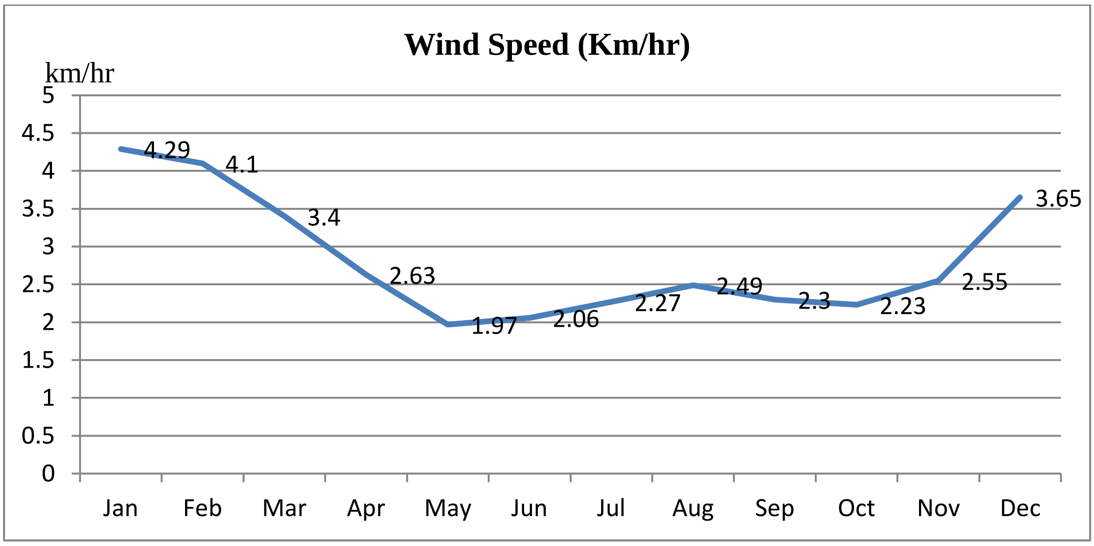


Figure 12. Average monthly wind speed of U-tapao River Basin, Thailand
Source: Southern Metrological Centre, Hatyai

Topography

Most of the land of the basin has the slope of less than 5 degree (64.40%), 18.40% of land has the slope between 5 to12 degrees, 13.56% of land has the slope between 12 to 20 degree and 3.63% of land has the slope between 20 to 35 degree. Overall, the average slope of the basin is about 6.89 degree. The elevation of the basin varies from place to place. The highest elevation with point from sea level is 925.73 m whereas the lowest elevation is -10.52 m below the sea level. Overall, 59.98% land of basin has the elevation less than 200 m, 24.87% land has the elevation between 200 to 400 m and 15.15% land has elevation more than 400m.

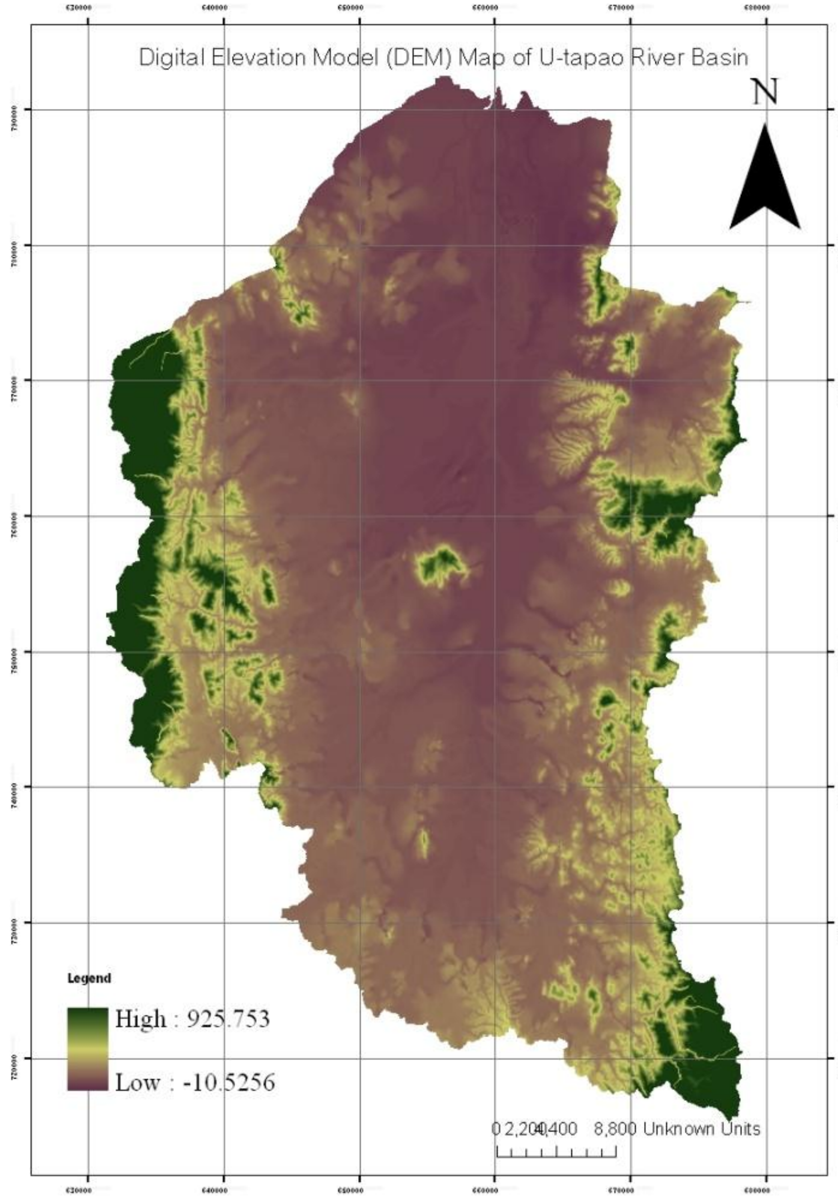


Figure 13. DEM Map of U-tapao River Basin, Thailand
Source: GEO-INRCNRE

Soil

About 65.44% land of the basin has soil depth above 150 cm, about 24.01% of land has soil depth between 50 to 150 cm and 10.55% of land of the basin has the soil depth less than 50 cm. Most of land of the basin (73.91%) has low fertility level, 25.70% land has moderate fertility level and only remaining 1.39% land has high fertility level. Regarding soil drainage, most of land (43.69%) is well drained, 22.57% land is moderately well drained, 11.6% of land is somewhat poorly drained, 18.45% land is poorly drained and 3.64% land is very poorly drained. Regarding pH value of soil, 37.5% of land has pH value within the range of 4.5 to 5.5, 58.7% land has pH value within range of 5.5 to 6.5, less than 2% land has pH value more than 6.5 and less than 1% land has pH value less than 4.5.

Socio-economic

Livelihood

The basin has always been rich in agricultural resources, rubber and rice production which are the main sources of livelihood and food for many of the small communities around the basin. There are wide range of non-agricultural occupation throughout the basin, such as rubber and seafood industries, tourism, transportation, and restaurants. The major agricultural occupations are: (a) Fishery: most people who live around lake earn their livelihoods from fishing. In recent years, however, because of declining in aquatic catch, many fishermen have been forced to find new occupation in the cities as factory workers and so on. (b) Aqua-farming: It grew rapidly and has been expanded to freshwater areas, even displacing some rice farms. The wastewater from shrimp farms is discharged into the river. (c) Rice farming: Rice farming is a traditional occupation of the people living around basin. However, in recent years, as a result of floods, droughts, and farmers moving to other occupations, most paddy fields have been converted to alternative uses such as shrimp farming, rubber planting, or residential areas. (d) Orchards and rubber plantations: Rubber has been one of the most important economic crops for a long time. Most fruit orchards with various types of trees grown together in the same area, depending on the suitability of the land and demand. (e) Pig farming: Pigs are an important source of meat in Thailand and there are many pig farms around basin. Most pig farms are small in size, run by household labor.

Problems of U-tapao river basin

Urbanization

The analysis of urban development in the basin during the 2000-2009 periods indicates that most of the urban growth occurred in the portion of basin where agriculture lands were available for new development. During this period, urban land increased more than two fold, from approximately 84.206 km^2 to approximately 180.589 km^2 (7.83% of the total basin area). Analyzing the land use data from 2000 to 2009, the residential land use was increased dramatically about 96.16%, especially after 2006. Expansion of Hatyai city and housing development were provoking factors of this dramatic increment. From 2000 to 2009, institutional land use changed from 10.94 km^2 to 26.06 km^2 whereas industrial land use changed from 10.05 km^2 to 16.87 km^2. Due to expansion of Hatyai airport, the transportation land use was also increased dramatically from 1.31 km^2 to 19.74 km^2. Overall, urban land use was increased dramatically after 2006 (Figure 14).

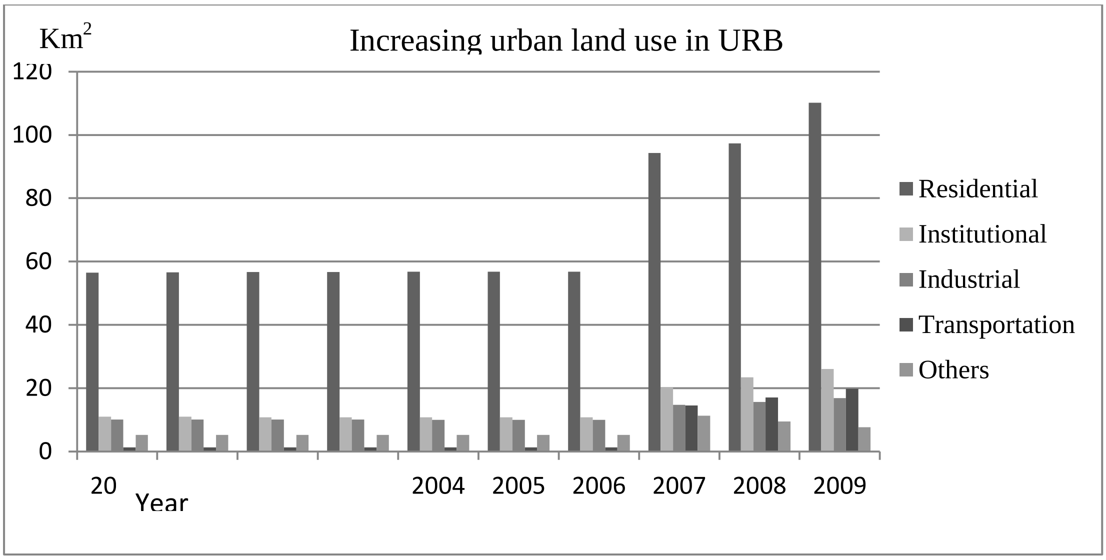


Figure 14. Increasing urban land uses from the year 2000 to 2009 in URB
Source: GEO-INRCNRE

Industrialization

Overall, most of the industries are located on the banks of river, 24.9 % industries are located in the upstream, 65% industries are located in midstream and 10.1% in downstream region. In Sadoo district; 8(10.49%) Concrete, 32(41.6%) Rubber, 14(18.2%) Furniture, 9(11.7%) Plastic, 2(2.6%) Metal, 3(3.9%) Service and 3(3.9%) Food industries are located. Similarly, in Klong Hoi Khog district; 4(80%) Concrete and 1(20%) Furniture industries are located. In Na Mom district; 1(8.3%) Concrete, 2(16.7%) Rubber, 2(16.7%) Furniture, 2(16.7%) Plastic and 2(16.7%) Food industries are located. In Hatyai district; 16(18.7%) Concrete, 36(19.6%) Rubber, 28(15.2%) Furniture, 13(7.1%) Plastic, 9(4.9%) Metal, 49(26.6%) Service and 24(13%) Food industries are located. In Bang Klam district; 5(16.1%) Concrete, 8(25.8%) Rubber, 8(25.8%) Furniture, 4(12.9%) Plastic, 5(16.1%) Service industries are located (Figure 15).

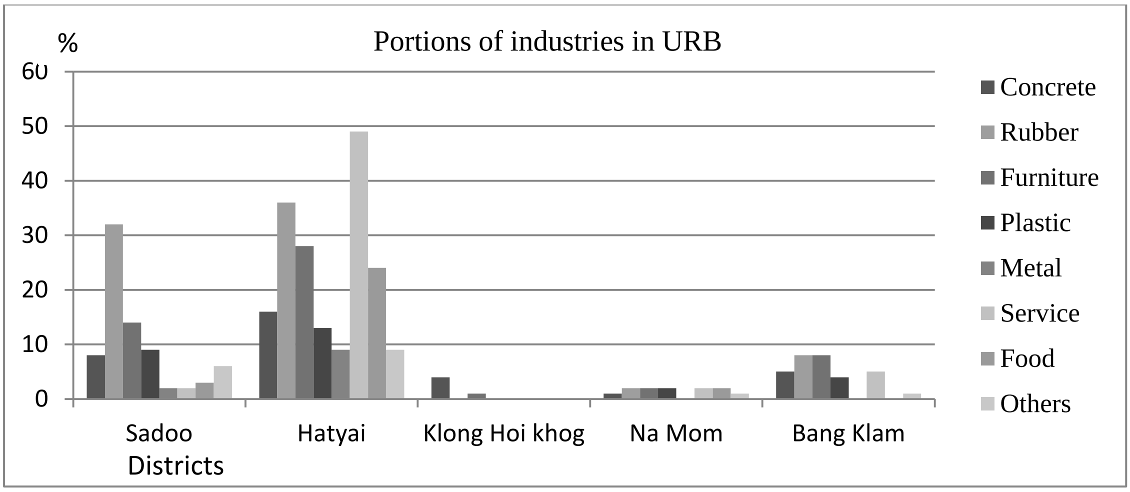


Figure 15. Portions of industries in five districts of URB
Source: GEO-INRCNRE

CHAPTER 4

RESEARCH METHODOLOGY –I

One of the purposes of this study was to explore the land use pattern and water quality of U-tapao river. Therefore, this study focused on the cause and effect relationship between land use pattern and water quality of river.

Types and sources of data

To analyze the relationship of land use and water quality, secondary data of water quality were collected from Regional Environmental Office-16, Songkhla and land use information were derived from the land use maps provided by Land Development Department, Thailand.

Water Quality Data: In this study, only secondary water quality data were gathered from Regional Environmental Office-16, Songkhla which is authentic and reliable organization of collecting and managing water quality information according to Thai Standard of Southern region of Thailand. The water quality parameters for this study were temperature (TEMP), pH, salinity (SAL), biological oxygen demand (BOD), dissolved oxygen (DO), electrical conductivity (EC), suspended solid (SS), dissolved solid (DS), total solid (TS), turbidity (TUR), total coliform bacteria (TCB), fecal coliform bacteria (FCB), ammonia (NH_3), Nitrite (NO_2), Nitrate (NO_3), and total phosphorous (TP).

Table 8
Three types of data collection framework of U-tapao river basin

Framework	Year	Number of stations	Parameters
I	2000-2009	9	pH, TEMP, BOD, DO, SS, EC
II	2007-2011	21	pH, TEMP, BOD, DO, EC, NH_3, FCB
III	2003-2009	3	pH, TEMP, BOD, DO, EC, NH_3, FCB, TCB, NO_2, NO_3

Source: Regional Environmental Office-16, Songkhla

Land Use: Land use types were broadly classified into four categories: 1) Agriculture, 2) Forest, 3) Urban, and 4) Water body. The land use information of the basin were derived from land use maps (2000, 2007 and 2009) provided by Land Development Department, Thailand and land use maps (2002 and 2006) provided by GEO- Informatics Research Center for Natural Resource and Environment (GEO-IRCNRE), Hatyai, Thailand, Thailand by ArcGIS software. For calculation of slope and elevation of land use structure, DEM map was used provided by GEO-IRCNRE. Land use descriptions of four land use types were as follows:

Agriculture: Agricultural land included paddy fields, field crops, perennial crops, orchard, horticulture, swidden cultivation, fishery and aquatic plants (Division of land use planning, Department of land use survey, Thailand).

Forest: Forest included evergreen forest, deciduous forest, forest plantation and disturbed forest (Division of land use planning, Department of land use survey, Thailand).

Urban: Urban included city, town & commercial land, village, institution land, transportation land, industrial land and others (Division of land use planning, Department of land use survey, Thailand).

Water body: Water body included natural water resources, wet land, mines, shrub & grass land, salt pan, rocky, beach and sand bar and others (Division of land use planning, Department of land use survey, Thailand).

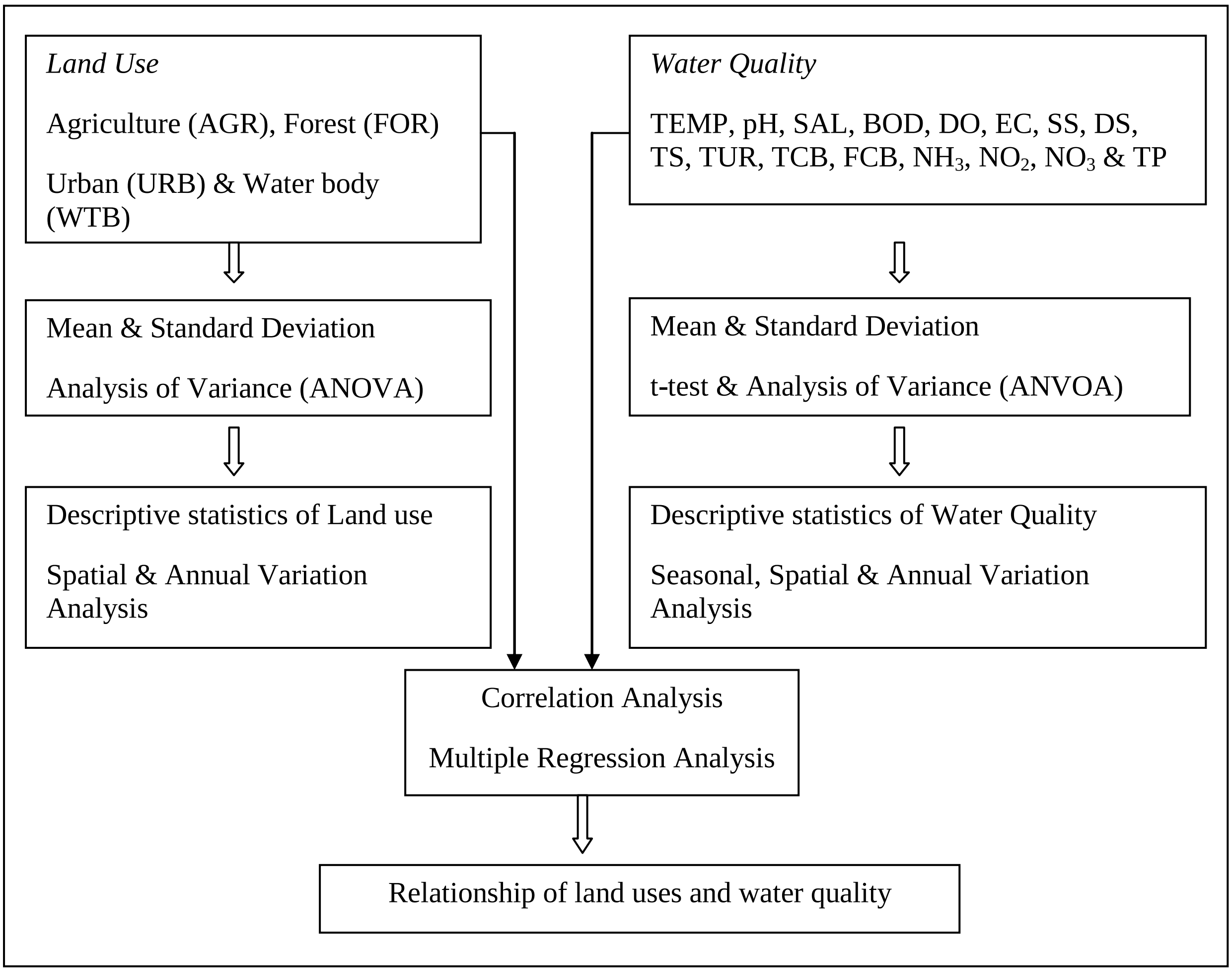


Figure 16. Research Methodology-I Framework

Analysis of Data

The data were analyzed using spatial and statistical analysis technique. First, the spatial data were overlaid in GIS to obtain basic information like percentage of land use for each period and each watershed, the percentage of land use changes between two periods, and the spatial distribution of changes. Then, the information obtained from the land use data was combined with the water quality data for statistical analysis. For the case of water quality, it is affected by land uses in the drainage area rather than within the limits of administrative region. Therefore, water quality data at a sampling site could be used to represent the water quality of its drainage area (Amiri & Namane, 2008). The study focused the historical impact of land use on surface water quality of river, so annual water quality is important. Therefore, all available data were organized in annual format. In this study, annual land use information of ten watersheds of the basin were linked to annual mean water quality data of ten corresponding monitoring stations of the river. Overall, the following statistical methods were used.

Descriptive statistical analysis: In order to describe fundamental characteristics of the water quality and land use of the basin, descriptive statistical methods like the measures of central tendency (arithmetic mean), the measures of dispersion (standard deviation and range), and the measures of skewness and kurtosis were used.

Correlation analysis: Correlation analyses were used to find the relationship between land uses and water quality parameters. For this, Pearson's correlation coefficient was used to evaluate the strength of relationship. Correlation coefficient values range from -1.00 to +1.00, where the negative sign indicates negative correlation and positive sign indicates positive correlation. Zero indicates no correlation. 95% confidence of interval or 5% level of significance was used for entire study.

Student t-test: Student t-test was used to compare the means of two samples. The paired sample t-test was used to compare mean values of water quality of two seasons. And, 5% level of significance was adjusted for this case as well.

Analysis of variance (ANOVA): The analysis of variance (ANOVA) was used the test mean difference of various groups. The ANOVA test assumes a null hypothesis, which states that there is no difference between the data within a data set. If the analysis is found to be statistically significant, then the null hypothesis is rejected for the alternative hypothesis. The alternative hypothesis states that the means of the data in the data set are different. Therefore, one-way ANOVA was used to determine the temporal (annual) and spatial variations of water quality parameters as well as land uses. Like correlation analysis and t-test, 5% level of significance was also adjusted in this analysis. For further analysis, the post-hoc test was also performed.

Multiple Regression Analysis (MRA): In this study, multiple regression analysis was used to fit the relationship of land uses with water quality parameters. The general purpose of multiple linear regression analysis is to quantify the relationship between several independent variables or predictors with a dependant variable (Attua, 2008). This method has been successfully used by different authors to establish statistical model for land use and water quality aspect (Jun & Zong-Guo, 2008; Tu & Xia, 2010; Korashey, 2009). In this study, water quality parameters were assigned as dependent variable and land use variables were assigned as independent variables. In the study, assumptions like expected value of residual terms should be zero with normal distribution and independent to each other, observation number should be more than parameter number, and there should not be multi-colinearity between or among independent variables were maintained.

The first-order simple linear regression equation as

$$Y = \beta_0+\beta_1X + \varepsilon$$

Where,

Y is the dependent variable

β_0 is the intercept parameter,

β_1 is the regression coefficient,

X is the independent variable

ε is a random error with mean, $E(\varepsilon) =0$ and variance$=\sigma^2$, error term is independent and normally distributed

Multiple Regression Equation as:

$$Y = \beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_3+\cdots\cdots\cdots\cdots+ \beta_k X_k + \varepsilon$$

Where

Y is dependent variable (Water Quality)

X_1 , X_2 ,………….., X_k are independent variables (Land Use)

β_0 is the intercept parameter

β_1 ………… β_k are regression coefficients

ε is random error.

The given equation can be written as $\mathbf{Y= X \beta_i + \varepsilon}$ in matrix notation where X is design matrix, β_i is coefficient vector of regression coefficient and ε is vector of random error. Regression coefficients can be estimated by Ordinary Least Square (OLS) method, the method is based on minimizing $\Sigma\, \varepsilon_i^2 = (Y- \hat{Y})^2$, square of difference between observed Y values with predicted $\hat{Y}$ values, predicted $\beta^{\wedge} = (X' X)^{-1} (X' Y)$ is solved by using OLS then β_0 ,β_1 ………… β_k can be calculated (Eydrane et al., 2005).

Model building

A key step in developing an appropriate multiple regression models is to select a method of model building and a set of the best model criteria. In model building operation; backward elimination, forward selection and stepwise methods are popular in regression analysis. Backward elimination begins by placing all the predictors under consideration in the model. It removes one at a time until reaching a point where the remaining variables all make significant partial contributions to predicting Y. For the case forward selection, it puts one variable at a time to the model until reaching a point where no remaining variable not yet in the model makes significant partial contribution to predicting Y. Stepwise method is a modification of forward selection that removes variable from the model if they lose their significance as other variables are added. In this study, stepwise method was applied for model building operation.

Validation of model

Regression analysis has been widely used to examine relationships between land use and water quality (Basnayat et al., 1999; Tu & Xia, 2006; Tran et al., 2010). Some authors constructed empirical regression models, but did not evaluate their predictive ability (Brett et al. 2005; Xiao & Ji 2007; Jager et al., 2011, Li et al., 2008; Yang & Jin, 2010). Few studies evaluated the predictive power of empirical regression models by separating huge data set for calibration and validation (Rothwell et al., 2010; Zampella, 2007). In this study, longitudinal cross validation approach was used to test the models; in addition, land use and water quality data of 2000-2008 were used to run model and data of 2009 were used to test the model. The performance of the model was tested by the average percentage of deviation (APD) approach on 2009 data set (Amiri & Nakane, 2008).

Data treatment

To adjust missing data of water quality, data were interpolated on the basis of previous and the following month values of the monitoring stations as well as the values of its upstream and downstream stations. Unusual or suspicious outliers were either re-estimated or removed from regression analysis. Normality of residuals of the models was examined by the Sharpio-Wilk test and the results suggested that the residuals of all models were normally distributed. Due to closure among land-use variables, colinearity may introduce a bias when relating the percentage of a particular land use to water-quality characteristics. A variance inflation factor (VIF) of <10 was the criterion used to indicated that multicolinearity was not adversely affecting model results.

CHAPTRE 5

RESULTS AND DISCUSSION –I

Water Quality Analysis

The water quality analysis is the first step of data analysis to explore the relationship between land use and water quality parameters. This part is mainly related to describe the basic characteristics of water quality of U-tapao river basin (URB), trend pattern, and seasonal, annual and spatial variations of water quality parameters. Water quality data, collected from different stations (Appendix A) from year 2001 to 2011 were analyzed. Descriptive statistics of 16 water quality variables are presented in Table 9.

Table 9
Descriptive statistics of water quality parameters (WQP) of URB (2001–2011)

WQP	Descriptive statistics of water quality parameters					
	Mean	SD	CV	Min	Max	Range
TEMP (ºC)	28.72	1.73	6.02	25.00	35.00	10
pH	6.82	0.19	2.78	2.9	13.5	10.6
EC (µs/cm)	571.00	336.28	58.89	0.00	152800	152800
SAL (ppt)	0.19	0.42	221.05	0.00	9.00	9.00
TUR (NTU)	64.09	68.41	106.74	3.30	357.00	353.70
SS(mg/L)	46.82	33.69	71.95	2.00	189.00	187.00
DS(mg/L)	151.22	73.11	48.34	5.00	333.00	328.00
TS(mg/L)	202.48	88.20	43.55	15.00	398.00	383.00
BOD(mg/L)	3.37	2.39	70.91	0.40	16.7	16.3
DO(mg/L)	4.16	1.49	35.81	0.50	11.2	10.7
TCB (mpn/100ml)	41,274	241,270	584.55	23	3,000,000	2,999,977
FCB (mpn/100ml)	17,251	49,254	285.51	23	500,000	49,9977
NH_3 (mg/L)	0.44	0.21	47.72	0.001	6.84	6.839
NO_3 (mg/L)	1.34	1.19	88.80	0.010	4.98	4.97
NO_2 (mg/L)	0.35	0.08	22.85	0.002	5.52	5.518
TP (mg/L)	1.01	2.68	265.34	0.010	13.13	13.12

Note: SD: standard deviation, CV: coefficient of variation, Min: Minimum value, Max: Maximum value

Descriptive analysis of water quality

Temperature (TEMP)

Temperature is one of the most important water quality parameters and it states the health of river also. The temperature of the water may affect both chemical and biological water characteristics and rates of many biological and chemical processes vary with temperature. Analyzing the monthly average temperature from the year 2007 to 2011, temperature is fluctuated within the around the range 26 ^{0}C to 32 ^{0}C (Figure 17). There was not so much difference on temperature in seasonal level, the average water temperature during wet season was 28.39 ^{0}C and during dry season was 29.37 ^{0}C. The dry season starts from February to April and these months have low rainfall because of the South China Sea wind. The hottest month is normally April, during this dry season; the amount of freshwater flowing into river is substantially lower than the rest of the year (Panapitukkul et al., 2005). Comparative analysis of monthly temperature data of 21 stations from year 2007 to 2011, showed that the lowest average temperature was in ST-2 (27.42 ^{0}C) which is located in upstream region whereas the highest average temperature was in ST-21 (30.33 ^{0}C) which is located in downstream region.

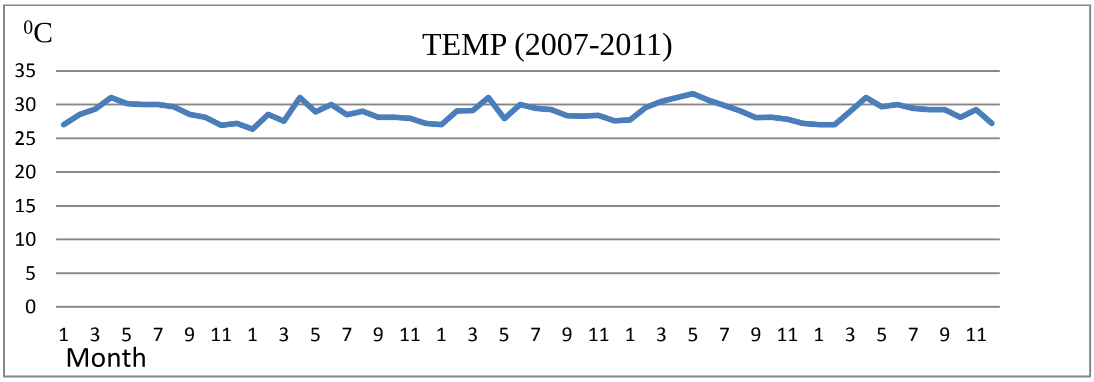


Figure 17. Monthly average temperature of URB from the year 2007 to 2011

pH, Electrical Conductivity (EC), Salinity(SAL) and Turbidity(TUR)

pH of water is a measure of the concentration of hydrogen ions in it and it is measured on a scale of 0.0 to 14.0 with 7.0 being neutral. Waters with pH values lower than 7.0 are increasingly acidic, while waters with pH values higher than 7.0 are more alkaline (or basic). Water with low pH (less than 6) or high pH (more than 11) can be harmful for aquatic life. Generally, pure water at 25ºC has a pH value of 7, while unpolluted surface water has a pH range between 6.5 to 8.5 (Duh et al., 2008). In the basin, the overall the mean and standard deviation of pH value of river water were 6.82 and 0.19 respectively; which is slightly acidic (pH < 7.0) and the difference between the highest and lowest value was 10.6. Most pH values fluctuated within the range between 6 to 8 and only exceptional data were found in July, August, and September 2007 (Figure 18). Even though, the average pH value of U-tapao river was slightly acidic which is the general limit of most of rivers and lakes, it ranged between 6.0 and 8.5. The average highest pH value was observed in ST-3 (7.15) and lowest value was observed in ST-7(6.56) and both are located on upstream region of the basin. There was slightly higher value of pH during wet season (6.92) compare to dry season (6.77).

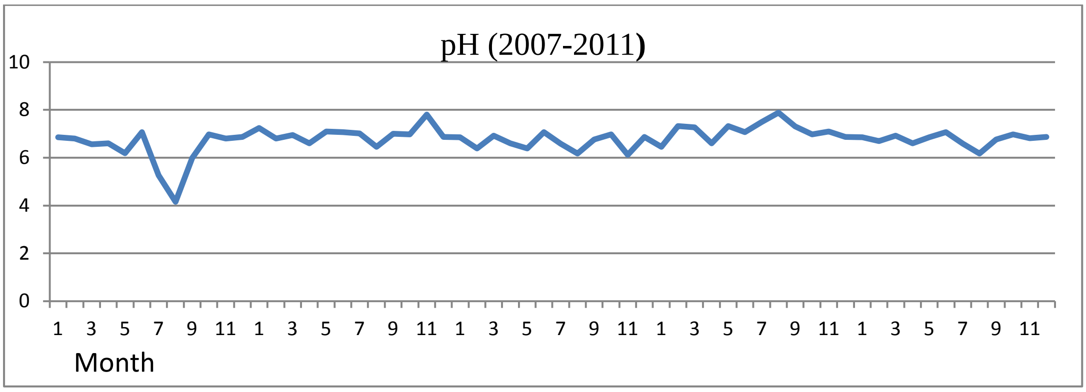


Figure 18. Monthly average pH value of URB from the year 2007 to 2011

EC of water is a measure of the ease with which an electrical current can pass through water. A high conductivity is a result of the presence of inorganic dissolved solids that carry a charge. EC of surface water is affected by both natural and anthropogenic factors. In the basin, overall mean and standard deviation of EC was 571.00µm/s and 336.28 µm/s, respectively with the range of 152800.00 µm/s (0-152800). Most of the EC data showed fluctuation around 0 to 500 µm/s from the year 2007 to 2011 with only exception for November 2007 and April and May 2010 due to unidentified causes in the river system (Figure 19). There was higher value of EC during wet season (688.65 µm/s) compared to dry season (376.88 µm/s). The average lower value of EC was observed in ST-1 (32.09 µm/s) and the higher value was observed in ST-20 (3016.5 µm/s) since saline water entered the river from sea.

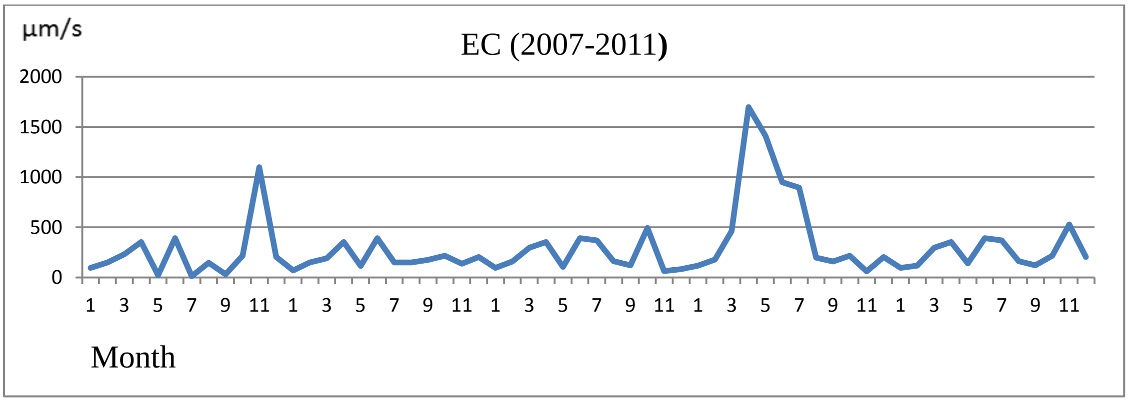


Figure 19. Monthly average EC of URB from the year 2007 to 2011

The mean and standard deviation of SAL were 0.19 ppt and 0.42 ppt respectively; and the difference between the highest value and the lowest value of SAL was 9.0 ppt. The highest SAL was observed during dry season (0.277 ppt) compared to wet season (0.131 ppt). Most of the downstream regions of the basin had higher salinity rather upstream regions since the river is connected with Songkhla lake (Lagoon).

Turbidity is a measure of the amount of suspended solids in surface water. Suspended solids include soil particles, algae, and microbes. The mean and standard deviation of TUR were 64.09 NTU and 68.41 NTU respectively; and the difference between the highest and the lowest value was 353.70 NTU. The variations on these variables were observed due to spatial and temporal changing factor of the basin. There was higher turbidity value during wet season (84.92 NTU) to as compared to dry season (32.38 NTU). The average highest value of turbidity was in ST-2 (114.10 NTU) and lowest value was in ST-3 (9.37 NTU) and both are located in upstream region of the basin.

Suspended solid (SS), Dissolved solid (DS) and Total solid (TS)

Suspended solid (SS) is also used to generalize water quality. It is generally supplied to surface water through soil erosion process (Shrestha & Kazama, 2007). Similarly, the overall mean and standard deviation of SS were 46.82 mg/L and 33.69 mg/L respectively; and the difference between the highest and the lowest value was 187 mg/L. The highest average SS was observed in wet season (44.59 mg/L) compared to dry season (38.82 mg/L). Similarly, mean and standard deviation of DS were 151.22 mg/L and 73.11 mg/L and the difference between the highest and the lowest value was 328 mg/L. The highest average DS was observed during dry season (169.20 mg/L) compared to wet season (148.97 mg/L). Overall, mean and standard deviation of TS were 202.48 mg/L and 88.20 mg/L respectively; and the difference between the highest and the lowest value was 383 mg/L.

Dissolved oxygen (DO) and Biological oxygen demand (BOD)

Generally, dissolved oxygen (DO) represents the amount of gaseous oxygen (O_2) in water, which is essential for aquatic organism. Low DO concentrations in river water indicate a degraded aquatic life (Wang et al., 2007). Mean and standard deviation of DO of river were 4.16 mg/L and 1.49 mg/L respectively; and the range of DO was 10.7 mg/L (0.5-11.2). DO is an also indicator of water body's ability to support aquatic life; hence it is essential for good water quality (Gyawali et al., 2011). Analyzing monthly data from year 2007 to 2011, all data fluctuated between 2 to 6 mg/L (Figure 20). The highest average value of DO was found in ST-1(5.81 mg/L) which is located in upstream region and the lowest value of DO was found in ST-20(2.97 mg/L) which is located in downstream region. The amount of DO is directly related to the population size and community of aerobic bacteria the aquatic system can support. Generally, DO>5.00 mg/L is considered favorable for growth and activity of most aquatic organism; DO<3 mg/L is stressful to most aquatic organism, while DO<2 mg/L does not support fish life (Yimer & Nengistou, 2010). Evaluating the mean concentration of DO of different monitoring stations, some areas of river showed a stressful condition for aquatic life. Regarding seasonal variation, a slightly higher value of DO was found during dry season (4.30 mg/L) compared with wet season (4.14 mg/L).

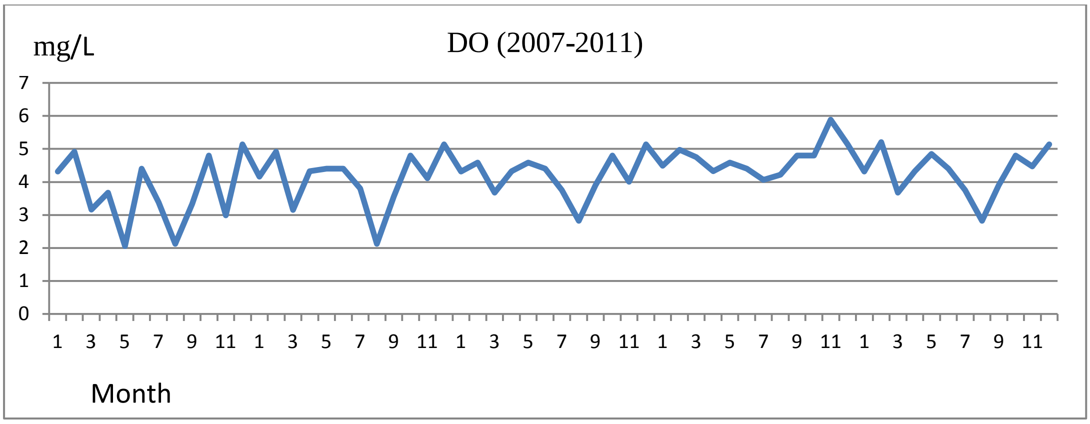


Figure 20. Monthly averages DO of URB from the year 2007 to 2011

Biological oxygen demand (BOD) represents the amount of oxygen required by microorganisms to degrade organic matter under aerobic condition (Jain & Singh, 2003).Overall mean and standard deviation of BOD of river were 3.37 mg/L and 2.39 mg/L respectively; and the range of the BOD was 16.3 mg/L (0.4-16.7). Analyzing monthly data of river from 2008 to 2011, most of data showed within the range between 2 to 5 mg/L. (Figure 21). The average BOD was 3.60 mg/L in dry season whereas the average BOD was 3.35 mg/L in wet season. The highest average value of BOD was found in ST-21 (4.33 mg/L) which is located in downstream region and the lowest value of BOD was found in ST-2 (2.37 mg/L) which is located in upstream region.

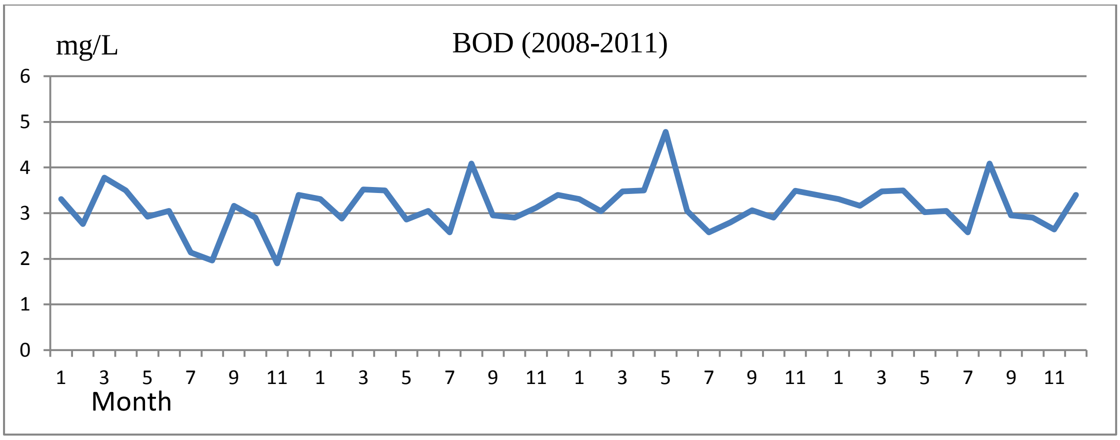


Figure 21. Monthly average BOD of URB from the year 2008 to 2011

Total Coliform Bacteria (TCB) and Fecal Coliform Bacteria (FCB)

For surface waters, total coliform, fecal coliform and E. coli are used to indicate the possible presence of harmful pathogens derived from human or animal waste. The concentration of coliform can originate from other sources such as soil, decaying vegetables, and industrial activities (Kuhn et al., 1997) but high concentration of fecal coliform in river might indicate pollution due to bad sanitation of human and animal fecal materials.

In the U-tapao river, the overall mean and standard deviation of TCB were 41,274 mpn/100ml and 241,270 mpn/100ml respectively; and the difference between the highest and the lowest value was 2,999,977 mpn/100ml. The higher value of TCB was found during wet season (63,770 mpn/100ml) compared to dry season (7,026 mpn/100ml). Similarly, the mean and standard deviation FCB were 17,251 mpn/100ml and 49,254 mpn/100ml respectively and the difference between the highest and the lowest value was 499,977 mpn/100ml. The higher value of FCB was found during wet season (5,471 mpn/100ml) compared to dry season (5,158 mpn/100ml). The average highest value of FCB was found in ST-15 (43,800 mpn/100ml) and the lowest value was found in ST-8 (1,580 mpn/100ml). Overall, the average presence of fecal coliform bacteria in all stations is quite high and it is not good to use water for domestic purpose without treatment.

Nutrients

Total nitrogen (TN) and Total phosphorous (TP) are common identifiers of nutrients in water. Nitrogen is vital element required for plant and animal growth. Nitrate and ammonia are two key forms of nitrogen in water. In natural conditions, the concentration of nitrate in water is 0.5 to 3mg/L, while the concentration of ammonia is around 3 mg/L (Jain & Singh, 2003). Phosphorous is abundant in sediment, but its concentration in the soluble form in surface water is relatively low. A common concentration of phosphorous in surface water is around 0.05 mg/L (Jain & Singh, 2003). Excessive amount of these nutrients is not good for river water quality aspect.

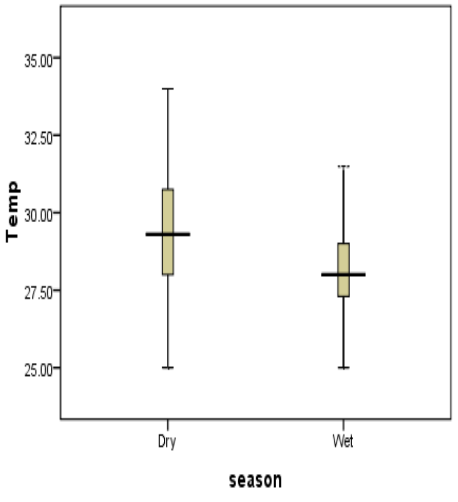
In U-tapao river, overall mean and standard deviation of NH_3 were 0.44 mg/L and 0.21 mg/L respectively; and the difference between the highest and the lowest value was 6.809 mg/L. The highest average value of NH_3 was found in ST-20 (1.243 mg/L) and the lowest value was found in ST-2 (0.027 mg/L). And, comparatively higher value of NH_3 was found during wet season (0.571 mg/L) rather than during dry season (0.258 mg/L). Similarly, the mean and standard deviation of NO_3 were 1.34 mg/L and 1.19 mg/L respectively; and the difference between the highest and the lowest value was 4.97 mg/L. And, comparatively higher value of NO_3 was found during dry season (1.89 mg/L) than during wet season (1.22 mg/L). Moreover, mean and standard deviation of NO_2 were 0.35 mg/L and 0.08 mg/L respectively; and the difference between the highest and the lowest value was 5.518 mg/L. Similarly, mean and standard deviation of TP were 1.01 mg/L and 2.68 mg/L respectively; and the difference between the highest and the lowest value was 13. 12 mg/L. Comparatively, the higher value of TP was found during wet season (1.01 mg/L) than during dry season (0.096 mg/L).

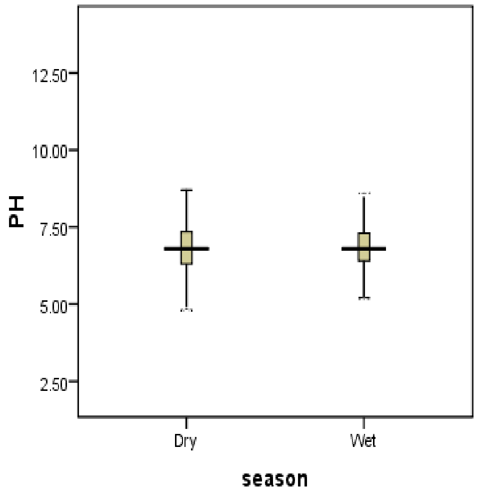
Seasonal, Annual, and Spatial variations of water quality parameters

Table 10

Seasonal variation of water quality

WQP	Dry Season	Wet season	t-value	p-value
TEMP	29.37±1.88	28.39±1.57	7.676	0.000
pH	6.77±0.84	6.92±1.10	-2.012	0.045
BOD	3.60±2.71	3.35±2.30	1.182	0.238
DO	4.30±1.58	4.14±1.46	1.415	0.157
EC	376.88±1407.43	688.65±4398.32	-1.162	0.246
SS	38.82±32.34	44.59±43.29	-0.536	0.595
DS	169.20±95.00	148.97±71.72	0.579	0.566
SAL	0.277±1.22	0.131±0.838	1.305	0.193
TUR	32.38±20.52	84.92±80.02	-5.256	0.000
TCB	7,026±8,567	63,770±30,902	-1.501	0.135
FCB	5,158±25,194	5,471±62,089	-2.632	0.009
NH_3	0.258±0.398	0.571±1.14	-2.097	0.038
NO_3	1.896±0.960	1.22±1.21	0.341	0.732
TP	0.962±1.35	1.01±2.82	-0.039	0.969





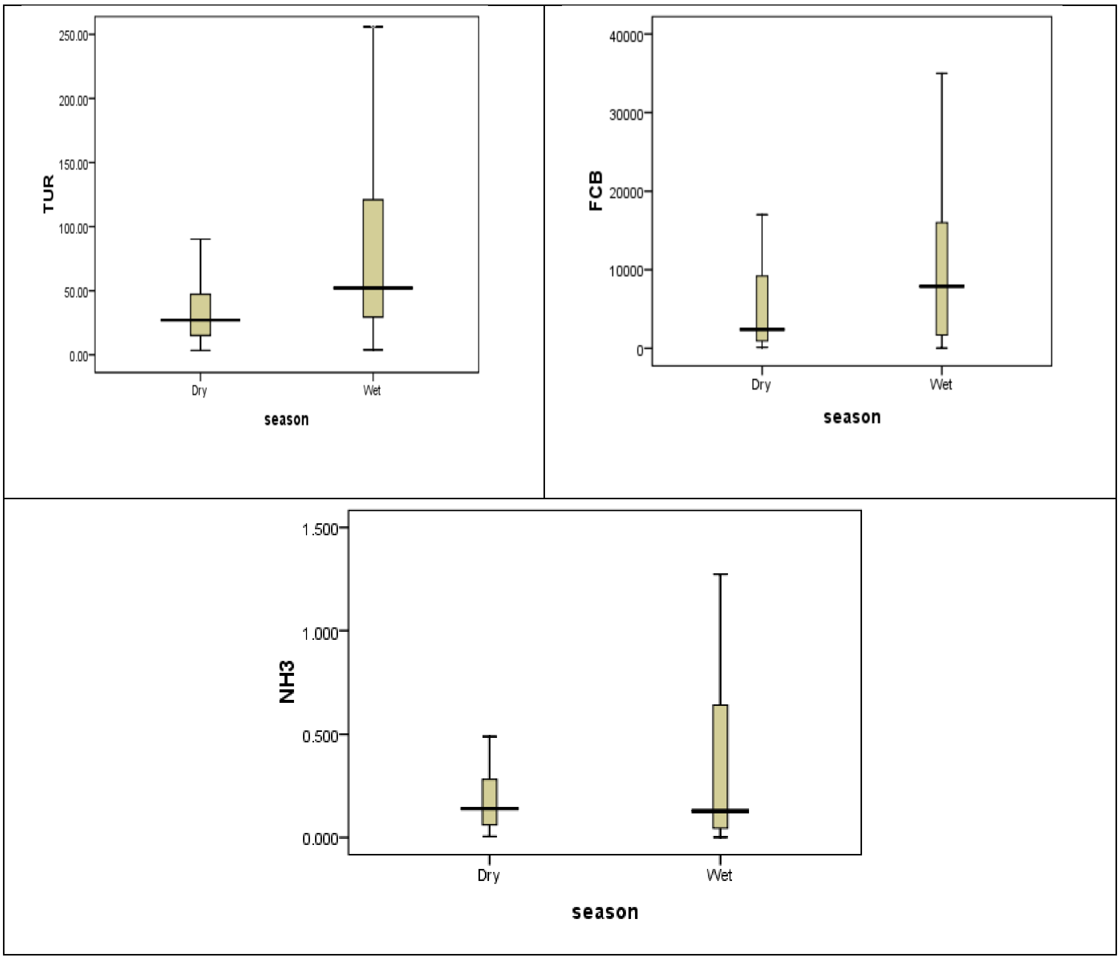


Figure 22. Seasonal variation of TEMP, pH, TUR, FCB and NH_3 of URB

In this study, TEMP showed significant seasonal variation and TEMP was significantly higher during dry season compared to wet season (Table 10). The highest average TEMP (30.88 ºC) was found in ST-20 during dry season whereas the lowest average TEMP (26.97 ºC) was found in ST-2 during wet season. For pH, there was significant difference on mean values in seasonal level, the highest average pH value (7.52) was found in ST-19 in wet season and the lowest average pH value (6.30) was found in ST-6 during dry season. Similarly, for TUR, there was significant difference on mean values with respect to seasonal level, the highest average TUR (187.90 NTU) was found in ST-2 during wet season whereas the lowest average TUR (9.13 NTU) was found in ST-3 during dry season. For FCB, there was significant difference on mean values in seasonal level, the highest average value of FCB (82,700 mpn/100ml) was found in ST-12 during wet season whereas the lowest average value of FCB (750 mpn/100ml) was found in ST-1 during dry season. In the urban watershed, fecal coliform levels were much higher during wet season than during the dry season. For NH_3, there was significant difference on mean values in seasonal level, the highest average value of NH_3 (0.151 mg/L) was found in ST-16 during wet season whereas the lowest average value of NH_3 (0.031 mg/L) was found in ST-9 during dry season. Other water quality parameters did not show significant difference on mean in seasonal level.

Annual variations

From annual variation analysis, there was significant difference on mean values of TEMP in annual level (F=15.064, $p<0.05$). From Tukey post-hoc analysis, the highest significant annual mean difference was found between years 2001 and 2010 (- 1.75 ºC, p=0.046). Annual trend of TEMP of the basin was observed by plotting the average annual TEMP values determined for all monitoring sites against year. For the case of TEMP, it was slightly increased from year 2001 (27.85 ºC) to 2011 (28.67 ºC) and the highest temperature was observed in year 2010 (29.60 ºC). From time series analysis, TEMP showed the rising trend line (Figure 23)

.

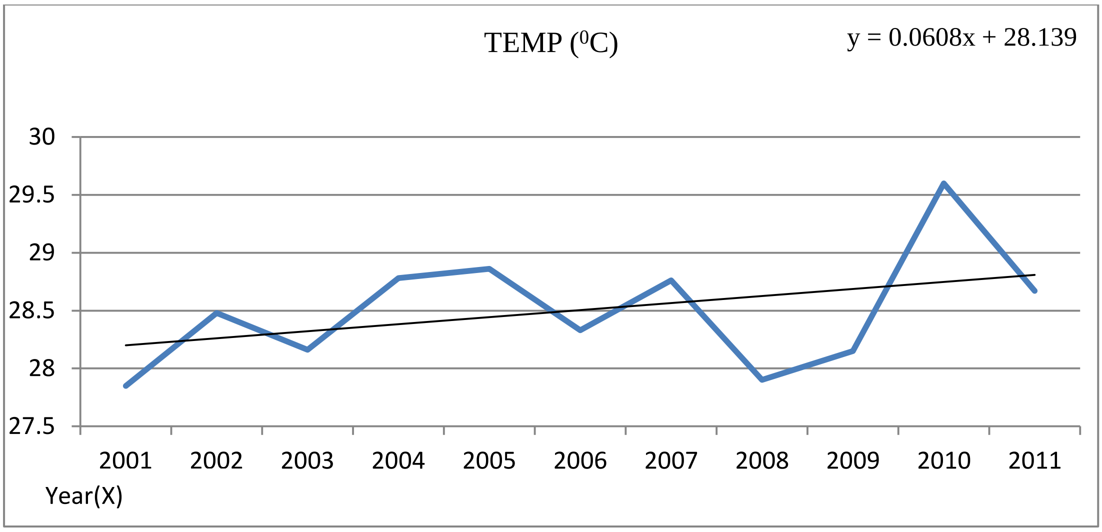


Figure 23. Trend line of TEMP of URB

For pH, there was significant difference on mean values of pH on annual level (F=20.042, p<0.05). From post-hoc analysis, the highest significant annual mean difference was found between years 2007 and 2010 (-1.15, p=0.00). For the case of pH, all annual average pH values are in the permissible range (6.0-8.5) and the lowest value was observed in year 2007 (6.09) and the highest value was observed in year 2010 (7.24). From trend analysis, pH value showed slightly declining trend (Figure 24).

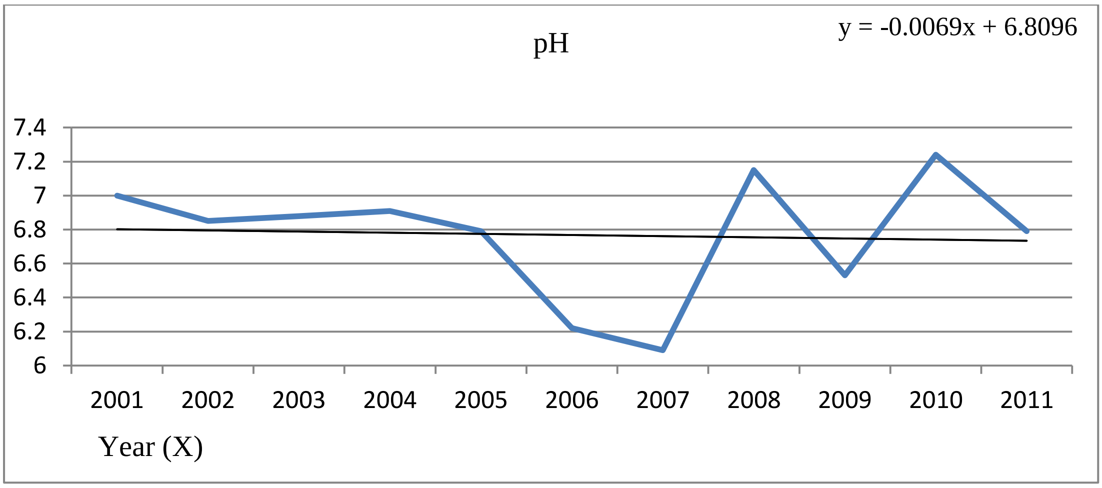


Figure 24. Trend line of pH value of URB

For BOD, there was significant difference on mean values on annual level (F=8.257, $p<0.05$). From post-hoc analysis, the highest significant annual mean difference was found between years 2001 and 2007 (-2.60 mg/L, p= 0.035). During trend analysis, BOD showed a slightly rising trend and the highest value was observed in year 2007 (5.00 mg/L) and the lowest value was observed in year 2001 (2.04 mg/L) (Figure 25).

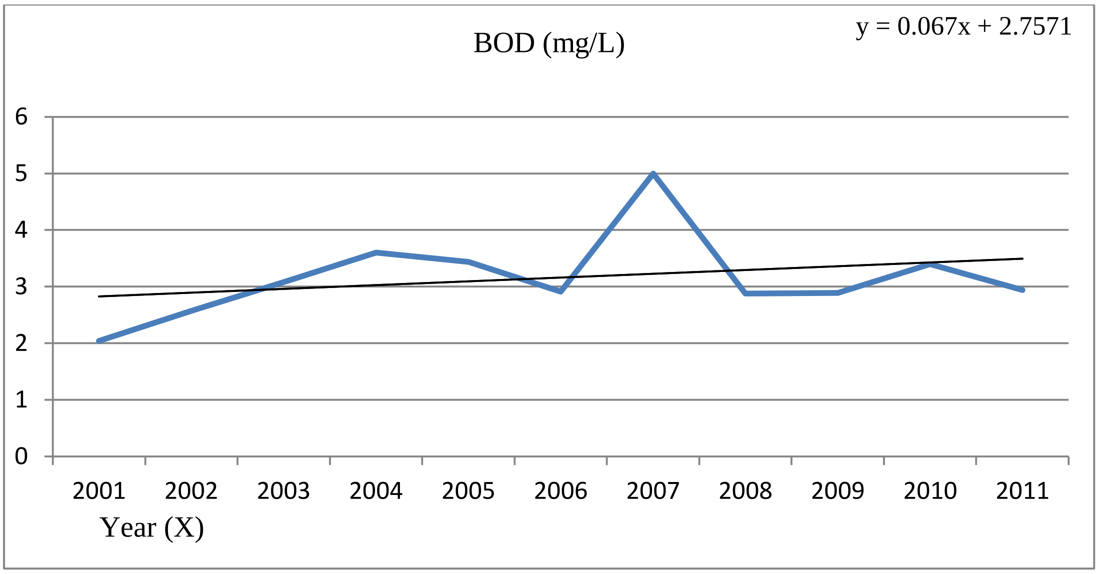


Figure 25. Trend line of BOD of URB

For DO, there was significant difference on mean values on annual level (F=18.472, $p<0.05$). From post-hoc analysis, the highest significant annul mean difference was found between years 2002 to 2010 (-1.88 mg/L, p=0.03). DO did not show any types of trend, in contrast to BOD. The highest value of DO was observed in year 2001 (5.22 mg/L) and the lowest value was observed in year 2007 (3.01 mg/L) (Figure 26).

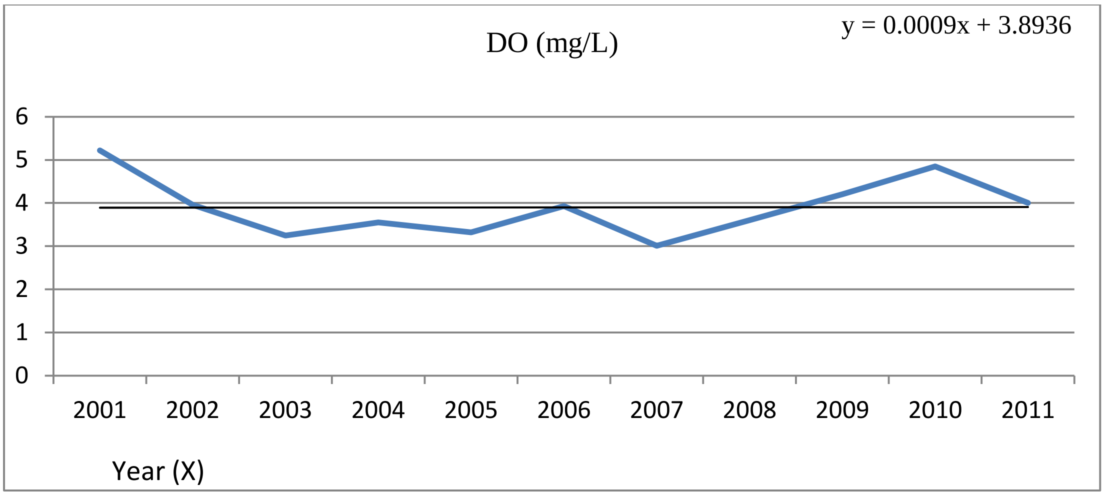


Figure 26. Trend line of DO of URB

Regarding EC, there was a significant difference on mean values on annual level (F=3.432, $p<0.05$). From post-hoc analysis, the highest significant annual mean difference was found between years 2007 and 2008 (2398.65 µs/cm, p=0.00). EC showed slightly declining trend. The highest value of EC was observed in year 2007 (2547.1 µs/cm) and the lowest value was observed in year 2001 (120.6 µs/cm) (Figure 27).

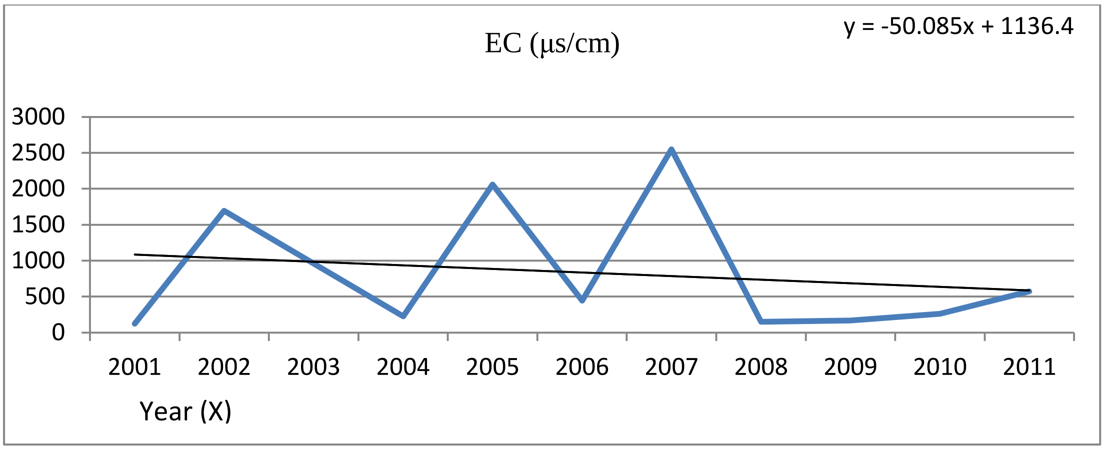


Figure 27. Trend line of EC of URB

For TUR, there was a significant difference on mean values on annual level (F=15.311, $p<0.05$). From post-hoc analysis, the highest significant annual mean difference was found between years 2006 and 2010 (-90.48 NTU, p=0.001). TUR showed slightly rising trend, the highest value was observed in year 2010 (138.68 NTU) and the lowest value was observed in year 2006 (57.3 NTU) (Figure 28).

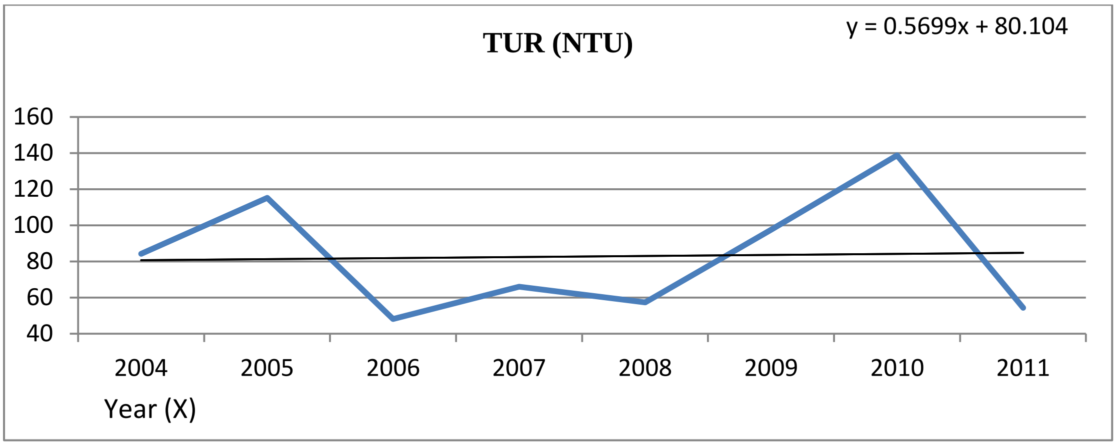


Figure 28. Trend line of TUR of URB

For NH_3, there was a significant difference on mean values on annual level (F=20.617, p<0.05). From post-hoc analysis, the highest significant annual mean difference was found between years 2008 and 2010 (-1.62 mg/L, p=0.00). NH_3 showed slightly rising trend, the highest value was observed in year 2008 (2.2 mg/L) and the lowest value was observed in year 2006 (0.59 mg/L) (Figure 29).

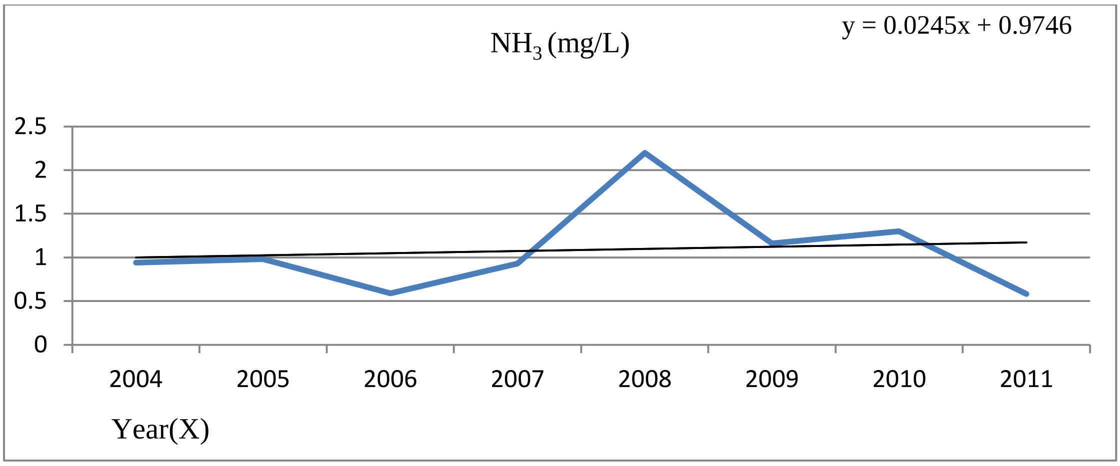


Figure 29. Trend line of NH_3 of URB

Spatial variations

To obtain information on the spatial distribution of water quality, the average value of whole year was calculated for each monitoring site. To assist visual interpretation, moving average curves were demonstrated in the figures. In this study, station ST-1 to ST-9 represented upstream region of basin and most of these areas were less affected from human activities, out of which, station ST-1 to ST-3 were the least affected regions. Station ST-10 to ST-17 represent midstream region of basin and most of these areas were affected by almost all types of pollution from residential, agricultural and industrial activities. Most of rubber processing and agricultural based industries are located along the station ST-12 to ST-17. Station ST-18 to ST-21 represent downstream region of basin and these regions were very much affected by agricultural, as well as shrimp and pig farming activities. Overall, most of the industries were located on the banks of river; 10.1% industries were located in the upstream, 65% industries were located in midstream and 24.9% were located in downstream region. And, the main commercial city, Hatyai is located in midstream region whereas traditional city, Songkhla is located in downstream region of the basin.

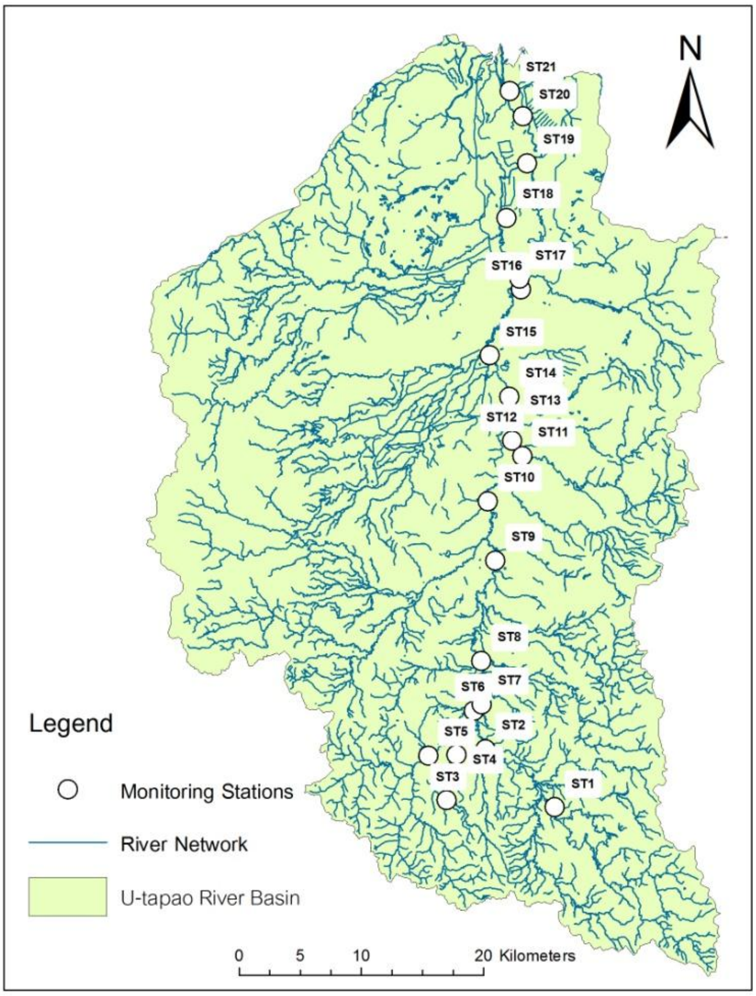


Figure 30. Twenty one monitoring stations along the river of URB
Source : GEO-IRCNRE

For the case of spatial variation, TEMP clearly showed the variation on spatial level. There was a significant difference on mean values of water temperature on spatial level (F=8.081, $p<0.05$). From post-hoc analysis the highest significance difference on mean values was found between stations ST-2 and ST-21 (-2.9 ºC, p=0.00). The average temperature of downstream region was greater than that of upstream region (Figure 31). From Figure 31, the lowest temperature was 27.4 ^{0}C at ST-2 which is located in upstream region whereas the highest average was 30.33 ^{0}C which is located in downstream region.

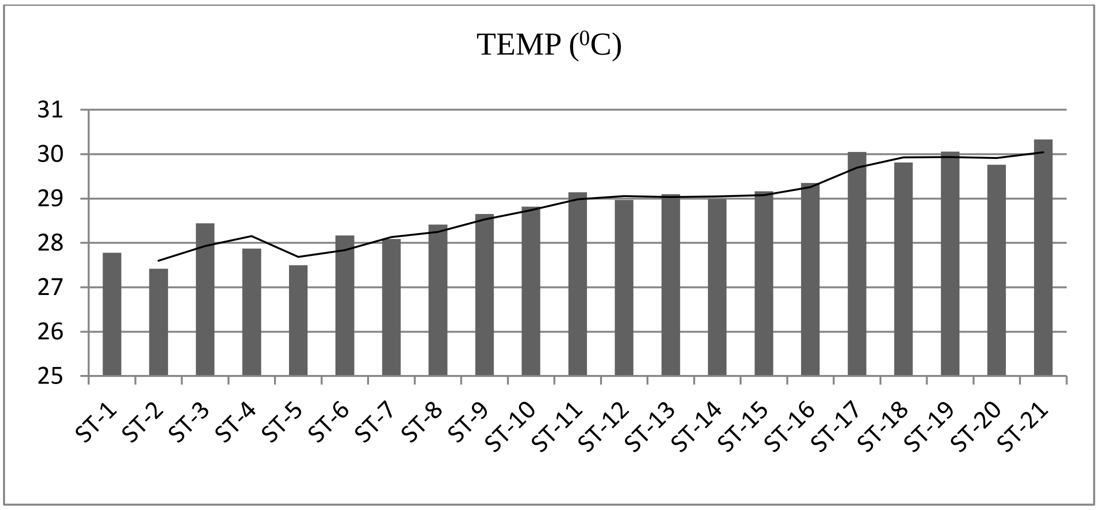


Figure 31. Distribution of TEMP in 21 water quality monitoring stations of URB

Regarding pH, there was no significant difference on mean values on spatial level. The average pH value in midstream region was slightly lower than in upstream and downstream regions (Figure 32). There was no clear trend of pH and the highest value was observed at ST-3 (7.15) and the lowest value was observed at ST-7 (6.56).

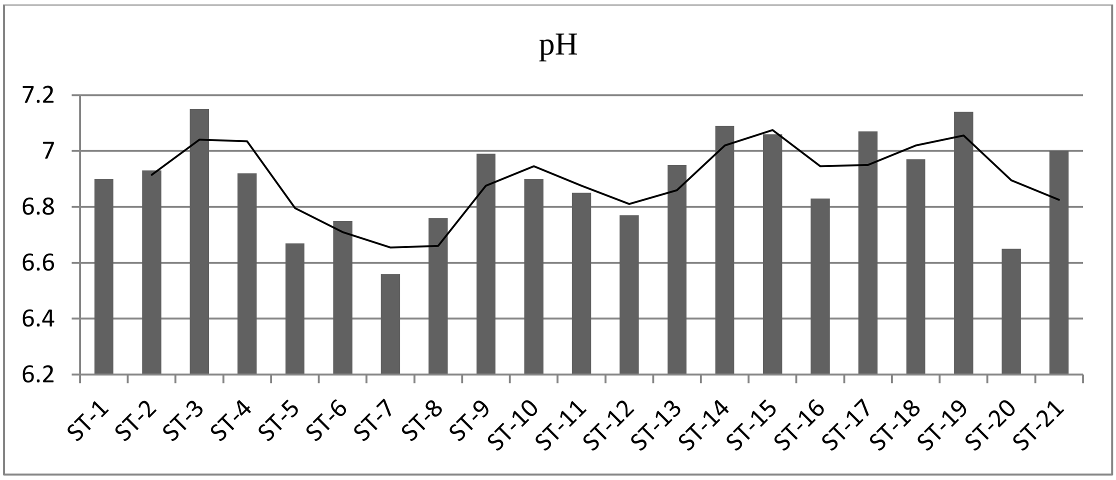


Figure 32. Distribution of pH in 21water quality monitoring stations of URB

Regarding BOD, there was no significant difference on mean values on spatial level but the average BOD was slightly higher in downstream region than in the upstream region (Figure 33) and the highest BOD was observed in ST-21 (4.33 mg/L) and the lowest was observed in ST-2 (2.37 mg/L).

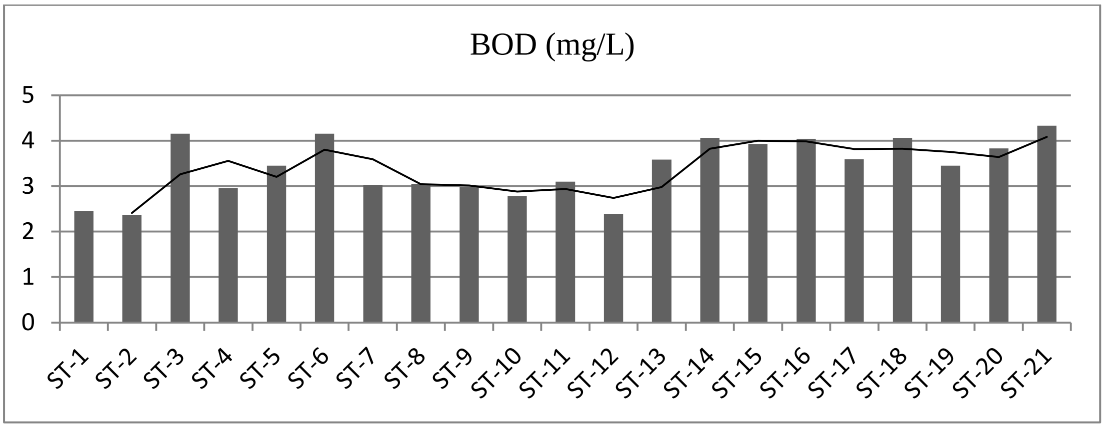


Figure 33. Distribution of BOD in 21 water quality monitoring stations of URB

Regarding DO, there was a significant difference on mean values of DO on spatial level (F= 10.933, $p<0.05$) and from post-hoc analysis the highest significant difference on mean values was found between stations ST-1 to ST-20 (2.84 mg/L). The average value of DO in downstream region was lower than in the upstream region (Figure 34).

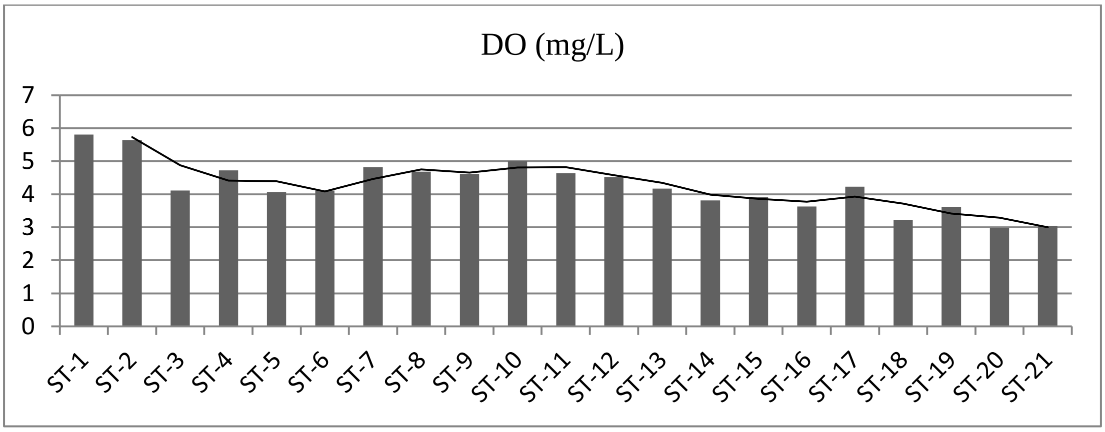


Figure 34. Distribution of DO in 21 water quality monitoring stations of URB

For the case of EC, there was no significant difference on mean values on spatial level but the values of EC were comparatively very high in ST-20 and ST-21 (Figure 35). For the case of SAL, there was a significant difference on mean values (F=4.979, p<0.05) and from post hoc analysis the highest significant mean difference was found between stations ST-1 and ST-21 (-2.5 ppt, p=0.00).

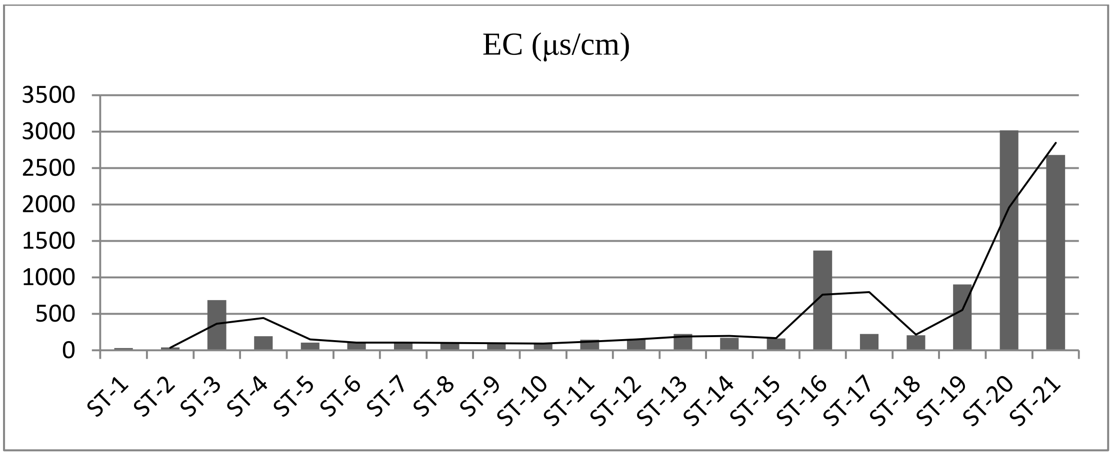


Figure 35. Distribution of EC in 21 water quality monitoring stations of URB

There was no significant difference on mean values on TUR on spatial level and comparatively low TUR was found in ST-3 and ST-4 (Figure 36).

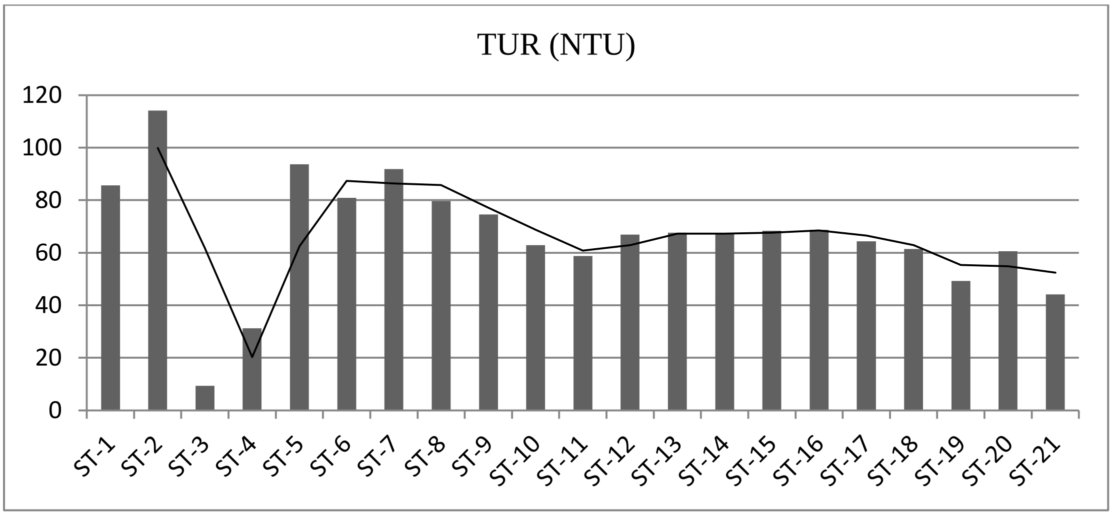


Figure 36. Distribution of TUR in 21 water quality monitoring stations of URB

There was no significant difference on mean values of FCB on spatial level but comparatively higher FCB was observed in stations ST-7, ST-9, ST-12, and ST-15 (Figure 37).

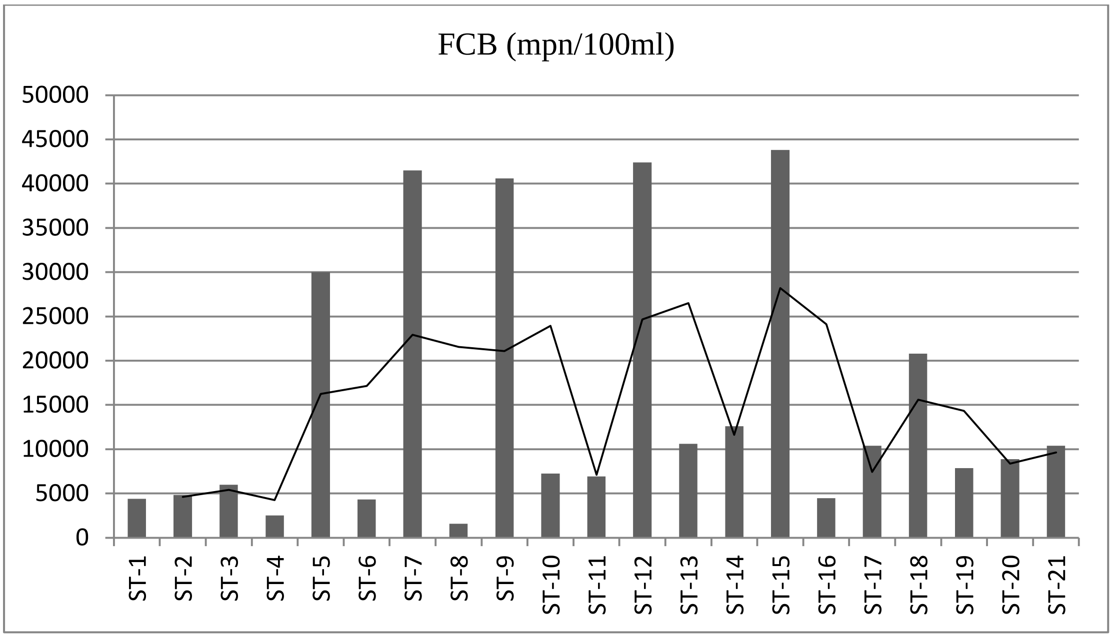


Figure 37. Distribution of FCB in 21 water quality monitoring stations of URB

For the case of NH_3, there was no significant difference on mean values on spatial level but comparatively higher NH_3 was found in ST-16 and ST-20 (Figure 38).

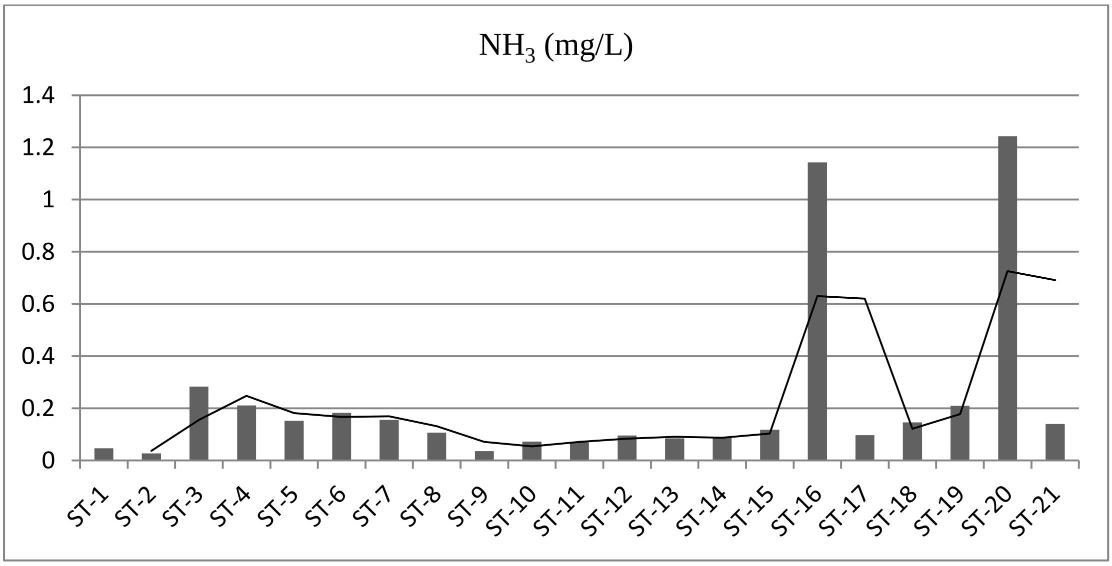


Figure 38. Distribution of NH_3 in 21 water quality monitoring stations of URB

Land use analysis

Land use analysis is the second step of data analysis part to explore the relationship between land use and water quality. This part is mainly related to describing the overall status of land use pattern of U-tapao river, analyzing the trend of land use, spatial and temporal variations of land use patterns.

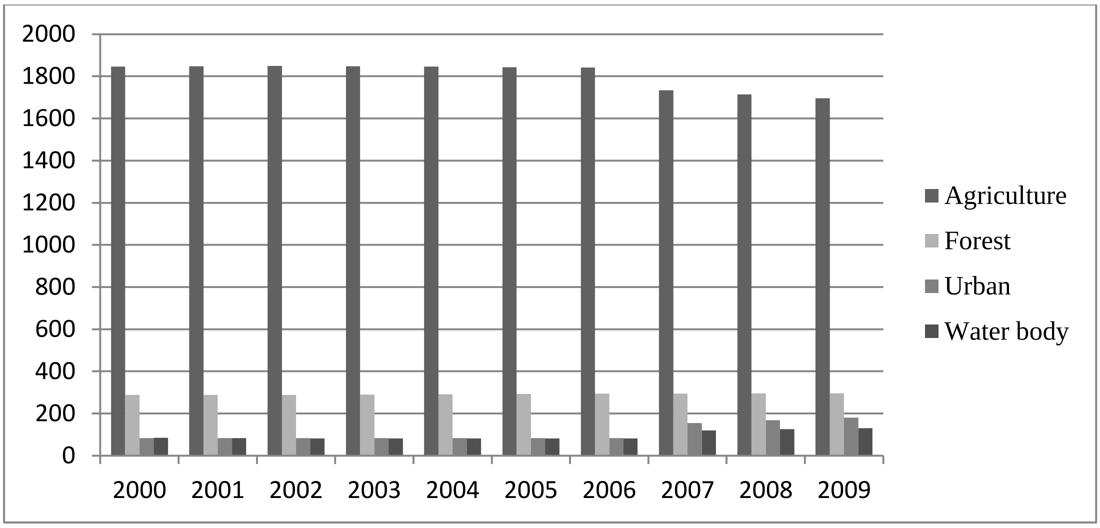


Figure 39. Land use distribution of URB from year 2000 to 2009 (in km^2)

Descriptive analysis of land use

Overall, the total area of the basin is 2305 km^2. Agricultural land is the dominating land of the basin; it covered about 1847.68 km^2 (80.16 %) of the basin in the year 2000 and 1696.71 km^2 (73.61%) in the year 2009 (Figure 39). Comparing different types of agricultural land use, rubber was dominating land use from the year 2000 to 2009 (Figure 40). The area of land use of rubber was 1654.99 km^2 (71.80%) in year the 2000 which decreased to 1513.69 (65.67%) in the year 2009 (Figure 40). The change of 6.13% land of rubber is the major land use change in the basin. The second dominating agricultural land use was paddy, the area of paddy field decreased from 112.5 km^2 (4.88 %) in the year 2000 to 103.73 km^2 (4.50%) in the year 2009 of total basin land (Figure 40). Similarly, land use for orchard decreased from 53.93 km^2 (2.34%) in the year 2000 to 30.42 km^2 (1.32%) in the year 2009; and land for farm house also decreased from 0.98 km^2 in the year 2000 to 0.83 km^2 in the year 2009 (Figure 40). In contrast, the area of palm-oil increased from 17.89 km^2 in the year 2000 to 24.30 km^2 in the year 2009 and fishery increased from 3.88 km^2 in the year 2000 to 9.47 km^2 in the year 2009 (Figure 40). Overall, the agricultural land decreased by 6.45% from the year 2000 to the year 2009 (Figure 39).

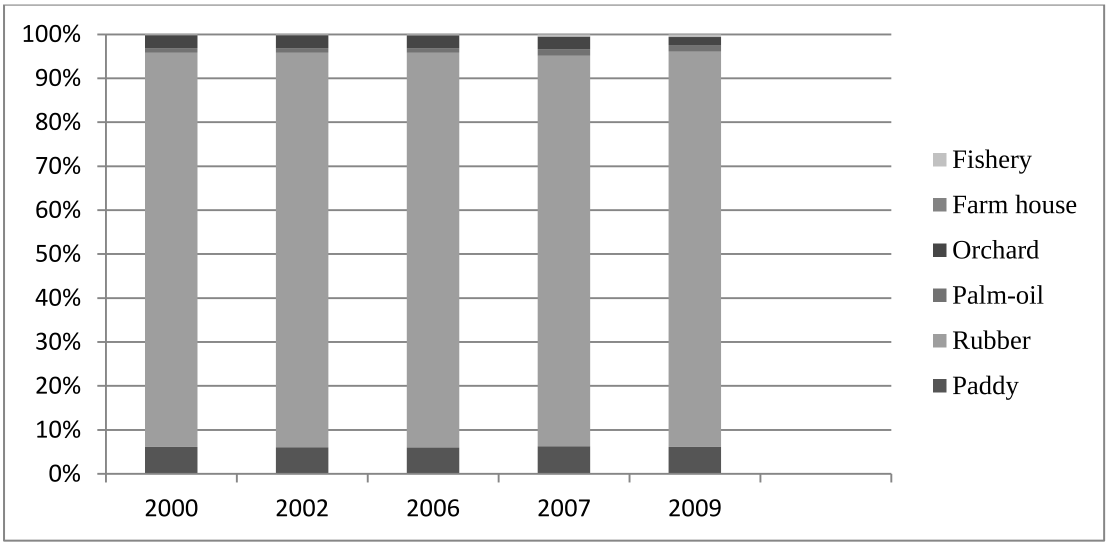


Figure 40. Agricultural land use distribution from the year 2000 to 2009

Like other developing land, the urban and built up land use of the basin also increased from 84.13 km^2 (3.65%) in the year 2000 to 209.06 km^2 (9.07%) in the year 2009 (Figure 41). Town and commercial land use increased from 20.92 km^2 in the year 2000 to 180.60 km^2 in the year 2009, village land use increased from 35.56 km^2 in the year 2000 to 85.89 km^2 in the year 2009 (Figure 41). Similarly, institutional land increased from 11.02 km^2 to 26.10 km^2 during this period. Transportation land use increased from 1.33 km^2 to 19.77 km^2 from the year 2000 to 2009, especially airport increased from 1.33 km^2 to 9.70 km^2. The recreational land use like for golf course also increased from 1.68 km^2 to 5.53 km^2 during this period (Figure 41).

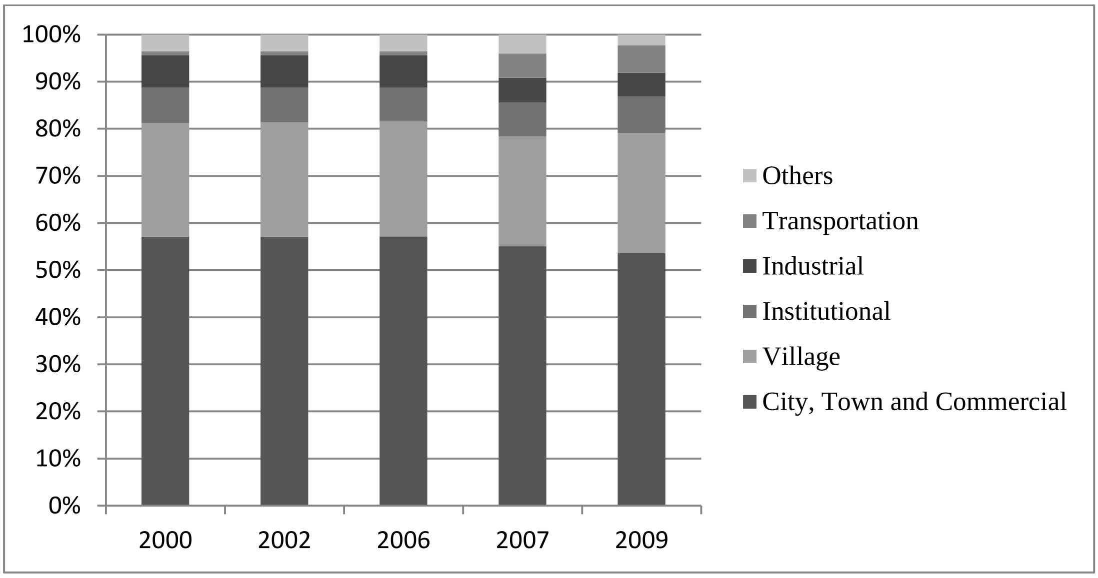


Figure 41. Urban built up land use distribution from the year 2000 to 2009

Forest land use increased from 288.63 km^2 (12.52%) to 296.52 km^2 (12.86%) from the year 2000 to 2009. Evergreen forest increased from 281.66 km^2 to 294.21 km^2 but distributed forest land decreased from 5.58 km^2 to 1.99 km^2 and planted forest land decreased from 1.39 km^2 to 0.32 km^2 during the same period (Figure 42).

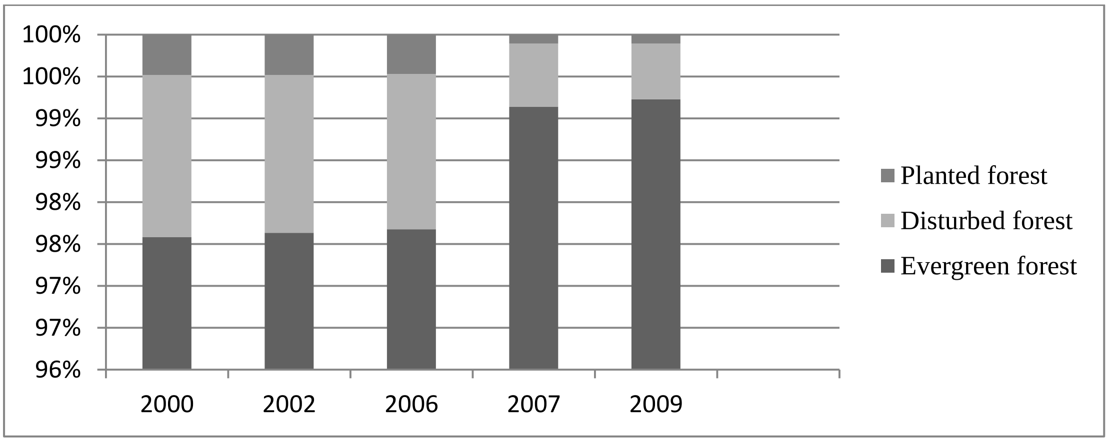


Figure 42. Forest land use distribution from the year 2000 to 2009

Total area of water body increased from 84.32 km^2 (3.65%) to 102.57 km^2 (4.45%) from year the 2000 to 2009. Natural resources like river and lake area increased from 4.33 km^2 to 7.24 km^2, reservoir increased from 8.10 km^2 to 17.25 km^2, grass and shrub land increased from 17.87 km^2 to 85.77 km^2 and laterpite area increased from 1.65 km^2 to 6.45 km^2. In contrast, the wet land decreased from 43.71 to 6.38 km^2 and mining area decreased from 8.88 km^2 to 8.11 km^2 (Figure 43).

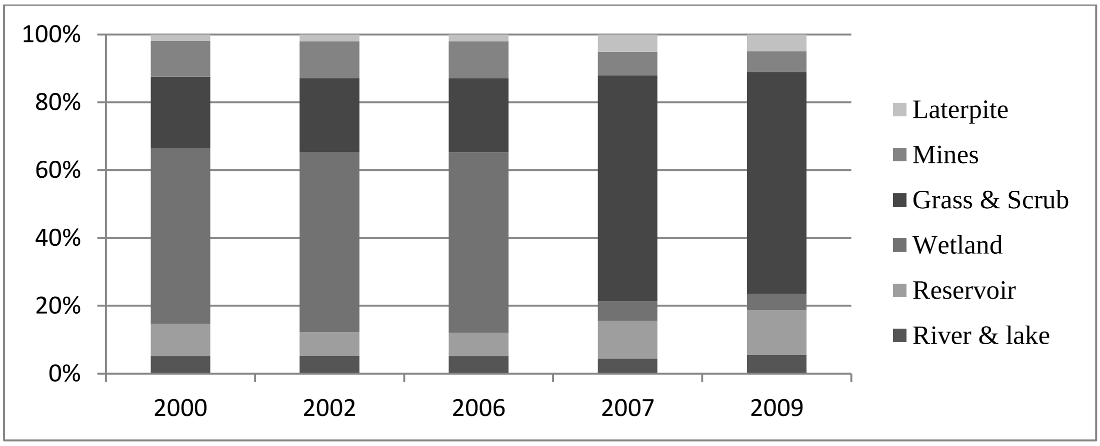


Figure 43. Water body distribution from the year 2000 to 2009

Land use change

In the year 2000, the percentage of agriculture, forest, urban, and water body were 80.16%, 12.86%, 3.65% and 3.65% respectively (Figure 39). Out of 80.16% land of agriculture, only 79.98% remained as agricultural land use but the remaining 0.17% land has been converted to forest land use, 0.02% to urban land and 0.005% to water body in the year 2002 (Table 11). Similarly, in the year 2000, the percentage of forest land use was 12.86%, out of which only 12.37% remained as forest land use and the remaining 0.14% land has been converted to agricultural land, 0.01% to urban and 0.18% to water body in the year 2002. Similarly, out of 3.65% of urban land use, only 3.52% remained as urban land but the remaining 0.001% land has been converted to agricultural land and 0.004% to water body. Similarly, out of 3.65% of water body, only 3.36% remained as water body and the remaining 0.11% land has been converted to agricultural land, 0.001% to forest and 0.001% to urban in the year 2002 (Table 11). Overall, agricultural land use increased by 0.078%, forest land use increased 0.013%, urban land use increased by 0.005% and only water body was decreased by 0.096% from the year 2000 to 2002 (Table 11).

In the year 2002, 80.23% of land was agricultural which decreased to 73.99% in the year 2006 with 3.25% converted to forest land, 1.64% to urban and 1.34% to water body. Out of the 12.54% land of forest in 2002, only 9.072% remained as forest in 2006 and the remaining 3.25% land has been converted to agricultural land, 0.15% to urban and 0.001% to water body. Similarly, in the year 2002, 3.65% land was urban but in year 2006, only 1.83% remained as urban and the remaining 2.01% land has been converted to agricultural land, 0.49% to forest and 0.01% to water body. Similarly, in the year 2002, only 3.55% land was for water body but in the year 2006, only 3.71% land remained as water body, and the remaining 0.66% land has been converted to agricultural land, 0.36% to forest, and 0.14% to urban land (Table 11).

In the year 2006, 79.66% of land was agricultural land but in the year 2007, out of total agricultural land, only 73.07% land remained as agricultural land and the remaining 1.97% was converted to forest land, 2.58% to urban and 2.03% to water body. Regarding forest, in the year 2006, there was only 12.82% land available for forest but in the year 2007, only 9.77% remained as forest, and the remaining 2.96% land was converted to agriculture, 0.10% land to urban and 0.004% land to water body. Similarly, in the year 2006, 3.78% land was urban but in the year 2007, only 2.94% remained as urban and the remaining 0.33% land was converted to agricultural land, 0.49% to forest and 0.01% to water body. Similarly, in the year 2006, only 3.71% land was as water body but in the year 2007, only 2.71% land remained as water body, and remaining 0.22% land was converted to agricultural land, 0.49% to forest, and 0.28% to urban land (Table 11).

In the year 2007, 76.6% of land was agricultural but in the year 2009, out of total agricultural land, only 73.45% land remained as agricultural land and the remaining 0.25% was converted to forest land, 2.34% to urban and 0.55% to water body. In the year 2007, there was only 12.74% land available for forest but in the year 2009, only 11.74% remained as forest, and the remaining 0.15% land was converted to agricultural land, 0.83% to urban and 0.007% to water body. Similarly, in the year 2007, 5.90% land was urban but in the year 2009, only 5.89% remained as urban land, and the remaining 0.001% land was converted to agricultural, 0.001% to forest and 0.008% to water body. Similarly, in the year 2007, only 4.76% land was available as water body, but in the year 2009, only 3.88% land remained as water body, and the remaining 0.001% was converted to agricultural land, 0.87% to forest, and 0.001% to urban land (Table 11).

Table 11

Land use change in URB from year the 2000 to 2009 (in %)

Year		2002			
2000		Agriculture	Forest	Urban	Water body
	Agriculture	79.982	0.172	0.021	0.005
	Forest	0.141	12.370	0.012	0.184
	Urban	0.001	0.000	3.521	0.004
	Water body	0.114	0.001	0.001	3.361
	Total	80.238	12.543	3.655	3.554
		2006			
2002	Agriculture	73.995	3.254	1.648	1.341
	Forest	3.317	9.072	0.153	0.001
	Urban	1.688	0.131	1.834	0.002
	Water body	0.666	0.367	0.148	2.373
	Total	79.666	12.824	3.783	3.717
		2007			
2006	Agriculture	73.075	1.974	2.580	2.037
	Forest	2.965	9.778	0.100	0.004
	Urban	0.336	0.498	2.940	0.009
	Water body	0.224	0.495	0.283	2.715
	Total	76.600	12.745	5.903	4.765
		2009			
2007	Agriculture	73.450	0.251	2.345	0.554
	Forest	0.158	11.742	0.838	0.007
	Urban	0.001	0.001	5.893	0.008
	Water body	0.001	0.876	0.001	3.887
	Total	73.61	12.87	9.077	4.456

Spatial and temporal variation of land use

For spatial variation analysis, the basin was divided into 10 mutually exclusive watersheds (Table 7). The largest watershed is WS- V (350.26 km^2) and the smallest being WS-IV (104. 99 km^2). In the year 2000, in WS-I, the percentage of agricultural land was 78.64%, the percentage of forest land was 11.18 %, the percentage of urban land was 2.15% and the percentage of water body was 8.03% (Figure 44). In the year 2009, in WS-I, the agricultural land decreased by 11.63%, forest land increased by 0.73%, urban land increased by 8.33% and water body increased by 2.57% (Table 12).

In 2000, there was 67.59% agricultural land in WS-II, 3.37 % land was forest, 13.82% land was urban and 14.84% land was water body. Comparing from the year 2000-2009, the agricultural land decreased by 1.71%, forest land increased by 0.67%, urban land increased by 8.55% and water body decreased by 7.51%. The percentage of agriculture, forest, urban, and water body in WS-III were 68.13%, 25.86%, 3.55% and 2.46% respectively. In the year 2009, agricultural land decreased by 7.89%, forest land decreased by 2.41%, urban land increased by 6.16%, and water body increased by 4.14%. The percentage of agriculture, forest, urban, and water body of WS-IV were 84.68%, 3.18%, 7.41% and 4.73% respectively in the year 2000 and in the year 2009, agricultural land decreased by 8.54%, forest land increased by 0.26%, urban land increased by 4.48% and water body increased by 3.80% (Table 12).

Moreover, in the year 2000, the percentage of agriculture, forest, urban, and water body of WS-V were 78.59%, 14.57%, 2.77% and 4.07%, respectively (Figure 44) and in the year 2009, the agricultural land decreased by 3.82%, forest land decreased by 4.71%, urban land increased by 4.41% and water body increased by 4.12% (Table 12). Similarly, in the year 2000, the percentage of agriculture, forest, urban and water body of WS-VI were 93.32%, 4.29%, 2.26% and 0.13% (Figure 44) , respectively and in the year 2009, the agricultural land decreased by 10.16%, forest land increased by 4.49%, urban land increased by 2.59% and water body increased by 3.08% (Table 12). In the year 2000, the percentage of agriculture, forest, urban and water body of WS-VII were 84.71%, 13.91%, 1.01% and 0.37% (Figure 44), respectively and in the year 2009, agricultural land decreased by 8.37%, forest land increased by 4.47%, urban land increased by 1.69% and water body increased by 2.21% (Table 12).

In the year 2000, the percentage of agriculture, forest, urban and water body of WS-VIII were 90.99%, 5.89%, 1.67% and 1.45%, respectively (Figure 44). Comparing from the year 2000 to 2009, the agricultural land decreased by 3.32%, forest land increased by 0.16%, urban land increased by 2.06% and water body increased by 1.10%. The percentage of agriculture, forest, urban and water body of WS-IX of the year 2000 were 96.72%, 0.34%, 2.68% and 0.27% respectively (Figure 44). Comparing from 2000 to 2009, the agricultural land decreased by 4.46%, forest land decreased by 0.01%, urban land increased by 2.89% and water body increased by 1.58% (Table 12). The percentage of agricultural, forest, urban and water body of WS-X in the year 2000 were 76.83%, 21.69%, 0.57% and 0.91% respectively (Figure 44). Comparing from 2000 to 2009, the agricultural land decreased by 8.47%, forest land increased by 2.93%, urban land increased by 0.78% and water body increased by 4.74% (Table 12).

Table 12

Ten watersheds of URB and percentage change of land use from 2000 to 2009

Watershed	Area (km^2)	Change in land use in percentage from 2000 to 2009			
		AGR	FOR	URB	WTB
WS- I	144.92	- 11.63	+ 0.73	+ 8.33	+ 2.57
WS-II	257.65	- 1.71	+ 0.67	+ 8.55	- 7.51
WS-III	338.68	- 7.89	-2.41	+6.16	+ 4.14
WS-IV	104.99	- 8.54	+ 0.26	+ 4.48	+ 3.80
WS-V	350.26	- 3.82	- 4.71	+ 4.41	+ 4.12
WS VI	164.29	- 10.16	+ 4.49	+ 2.59	+ 3.08
WS-VII	326.59	- 8.37	+ 4.47	+ 1.69	+ 2.21
WS-VIII	184.91	- 3.32	+ 0.16	+ 2.06	+ 1.10
WS-IX	172.32	- 4.46	-0.01	+ 2.89	+ 1.58
WS-X	260.39	- 8.47	+ 2.93	+ 0.78	+ 4.74

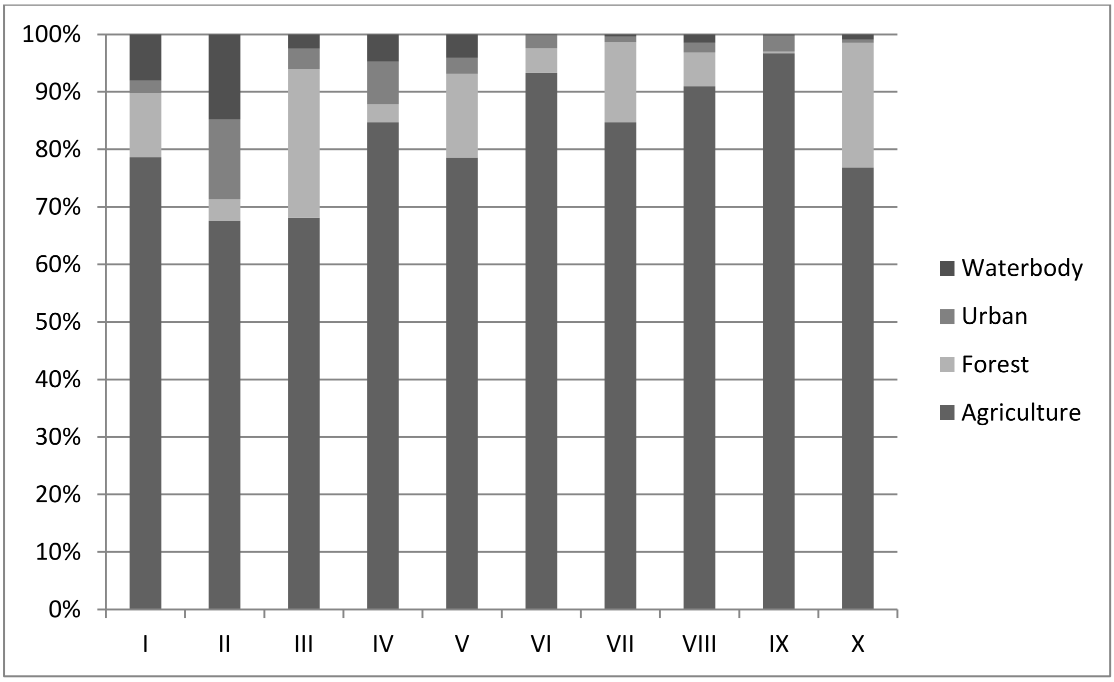


Figure 44. Land use distribution on 10 watersheds of URB in the year 2000

Analyzing the variance, using One-way ANOVA, there was no significant difference on mean values of percentage of all land uses in temporal level but there was a significant difference on spatial level. Regarding agricultural land use, there was significant difference on mean values of agricultural land in spatial level (F=93.00, p<0.05). From post-hoc analysis, the highest significant mean percentage difference of agricultural land use was observed between watershed II and watershed IX. In the case of forest land use, there was significant difference between mean values in spatial level (F=379.97, $p<0.05$) and the highest significant mean difference was observed between watershed III and watershed IX. In the case of urban land use, there was significant difference between mean values in spatial level (F=36.91, $p<0.05$) and the highest significant mean difference was observed between watershed II and watershed X. In the case of water body, there was significant difference between mean values in spatial level (F=28.87, $p<0.05$) and the highest significant mean difference was observed between watershed II and watershed VI.

The relationship between land use and water quality

Correlation analysis of land use and water quality

Many studies demonstrate that surface water quality has deteriorated noticeably in many parts of world due to poor land use practice and indicate the strong relationships between declining water quality and increasing agricultural and urban lands in catchment scale (Basnyat et al., 1999). Tong and Chang (2002) found that increment in agricultural land had a strong positive correlation with conductivity and pH but a negative correlation with heavy metals, while increment in residential land had a positive correlation with heavy metals, biological oxygen demand, and conductivity in the watersheds of Ohio State, USA. Similarly, Li et al. (2008) demonstrated that temperature had negative correlation with vegetation and bare land, pH had negative correlation with urban land and nitrite had positive correlation with bare land in Han River Basin, China. Ahearn et al. (2005) demonstrated that nitrite and total suspended solid had positive correlation with agriculture, urban and grass land and negative correlation with forest land in Sierra Nevada, California. Due to the fact that some correlation exists between pollution loading and land use, there is always potential for improving water quality with proper land-use management practices. This study also tried to find the relationship between land uses of the basin and water quality parameters of U-tapao river. For correlation analysis, land use information of ten watersheds was linked water quality data of corresponding monitoring stations. The correlation coefficient of between land uses and water quality parameters were presented in Table 13 below.

Table 13
Correlation coefficient between land use and water quality parameters

WQP	AGR	FOR	URB	WTB
TEMP	**-0.588**	**0.202**	**0.491**	**0.423**
pH	0.149	-0.117	-0.143	0.023
EC	-0.034	0.006	-0.102	0.162
DO	**0.378**	-0.083	**-0.245**	**-0.411**
BOD	**-0.422**	0.183	**0.246**	**0.347**
SS	**-0.254**	-0.075	**0.297**	0.002
DS	**-0.714**	**0.366**	**0.402**	**0.340**
TUR	0.181	0.219	-0.360	-0.124
FCB	-0.239	0.221	**0.352**	**-0.615**
TP	-0.180	0.250	0.037	-0.314
NO_3	-0.241	-0.319	**0.399**	0.340
NO_2	0.174	**-0.381**	0.274	-0.162
NH_3	0.018	-0.270	0.165	0.259

Note: **Bold** ($p<0.05$)

Results from the correlation analysis indicated that land-use types were significantly correlated with many water quality variables in the watershed scale (Table 13). For example, TEMP had significant negative correlation with agriculture and positive correlation with urban, forest, and water body (r = -0.588, 0.491, 0.202, and 0.423). BOD had significant negative correlation with agriculture and positive correlation urban and water body (r= - 0.422, 0.246, & 0.347). DO had significant positive correlation with agriculture and negative correlation urban and water body (r= 0.378, -0.245, & -0.411). These results suggest that the changing pattern of local urban and agricultural lands could be the primary driving forces behind the variations in DO, BOD, and TEMP.

DS had significant negative correlation with agriculture and positive correlation with forest, urban and water body (r= -0.714, 0.366, 0.402, & 0.340) and SS had significant negative correlation with agriculture and positive correlation with urban land use (r= -0.254 & 0.297). Generally higher SS can be observed with higher runoff where soil can be easily eroded (Ahearn et al., 2005; Braskerud, 2002). Industrial and domestic sewage discharged into surface water in urban areas lead to higher SS than other areas (Wang et al., 2007).Since surface water contamination is highly dependent on storm water runoff; it is not surprising that contaminants located in urban land use are more likely to reach water bodies. It was observed during field surveys that the urban sites in this study had very little or no vegetated riparian zone, thereby increasing the probability that concentrations of these contaminants increase after storm events. Runoff from urban land and effluents from industrial areas are major sources of fine sediment in river systems. The results indicate that mean concentrations of solid particles are most strongly linked to urban cover, suggesting that anthropogenic sources are the major contributor to fine sediment delivery in the basin (Rothwell, 2010).

FCB had significant positive correlation with urban land (r= 0.352) whereas it had significant negative correlation with water body (r = - 0.615).

Generally, urban land use and agricultural land use seem to yield the highest concentrations of fecal coliform in nearby surface waters (Mallin et al., 2000; Mehaffey et al., 2005; Shoonover et al., 2005). In urban watersheds, a strong correlation exists between the percent impervious surfaces in the watershed and mean fecal coliform levels in surface waters (Shoonover et al,. 2005; Young & Thackston, 1999). Mallin et al. (2000) also found a similar strong correlation between population density and mean fecal coliform levels in surface waters. Fecal coliform are consistently higher during both base flow and high flow periods in urban watersheds compared to other land uses (Shoonover et al., 2005). The number of domestic animals in an urban watershed may be another cause of elevated fecal coliform levels (Mallin et al., 2000; Young & Thackston, 1999). Young and Thackston (1999) found that high levels of fecal coliform and E. coli in urban watersheds were the result of animal sources rather than that of human.

NO_3 had significant positive correlation with urban (r= 0.399) and NO_2 had significant negative correlation with forest (r = -0.381). Nitrogen in surface water comes through several means; agricultural areas and grasslands are the major contributors. And discharged wastewater from a treatment plan also contributes to nitrogen concentration in surface water (Ahearn et al., 2005). On the contrary, denitrification in wetlands, riparian forests, and grasslands could reduce the nitrogen concentration of surface water (Hayakawa et al., 2006). Woli et al. (2008) suggest that the concentration of nutrients in surface water is not necessarily related to agricultural land use but more to the proportion of urban areas.

Regression analysis

In previous literatures, many methods and techniques were used to link land uses and water quality and to predict water quality parameters. Ha & Stenstorm (2003) used neural network approach to link land use and water quality as well as predict water quality parameters on the basis of land uses. Similarly, Kalin et al. (2009) used neural network approach to predict water quality parameters like total dissolved solid (TDS), Nitrate (NO_3), Sodium (Na) and Potassium (K) in West Georgia, United States. Since, the neural network approach is limiting case of regression model and its complexity, this concept is seldom used to link land use and water quality parameters. Some researcher tried to use factor analysis to explain land uses and water quality. Yu et al. (2012) used both factory analysis (FA) and principal component analyses reduce the number of land use matrices to link land use and water quality parameters. Lee et al. (2010) tried to link land use and water quality parameters by using principal component analysis in South Korea. To explain the relationship of land uses and water quality by factor analysis is good approach but it cannot be used to predict the water quality on the basis of land use parameters. For this reason, correlation and regression analysis are popular methods even they need a large set of data. Due to simplicity & flexibility, regression models were frequently used around the globe to predict water quality parameters on the basis of land uses (Bahar et al., 2008; Azyana & Norulaini, 2012; Amiri & Nakane, 2008; Sliva & Williams, 2001; Nakane & Haidery, 2010; Li et al., 2009; Tong & Chen, 2002; Tu, 2011).

In this study, the sub-watershed (Sub-basin) approach was used to link land uses with water quality parameters by multiple regression analysis. Water quality variables were assigned as dependent variables and land use variables were assigned as independent variable. To develop multiple regression models, some basic principles have to follow. For the case of sampling size, the number of cases substantially exceeds the number of predictor's variables. In this study, the percentage of agriculture land, forest land, urban land and water body were assigned as independent variables and the number of cases are exceed to the number of independent variables. Since, regression coefficients are independent of change of origin but not of scale. In this study, the values of all land use parameters were assigned in percentage. For regression analysis, the residual should be independent and distributed normally. In this case, the normality of residuals were checked by Sharpio-Wilk test and found that all residual values were normally distributed.

In regression analysis, the selection of the appropriate model is also an important part. Generally, the most of researchers prefer the coefficient of determination (R^2) criteria for selection of the model that means the higher value of R^2 recommend the selection of that model (Huang et al., 2011; Yang et al., 2006; Zampella, 2007; Silva & Williams, 2001). Sometime, R^2 gives upward biasness, for this reason, some researchers prefers Adjusted R^2 instead of R^2 criteria (Li et al., 2008; Li et al., 2009). Some researchers used the concept of the difference between R^2 and Adjusted R^2 should be less than 5% criteria. Some researchers used the joint R^2, MSE and Mallow's C_m statistics (R^2 should be large and C_m should be less) to select the appropriate model. Beside these, F-test and t-test approaches could be used to select the appropriate model (Nakane & Haidary, 2010). The F-test allows to conclude that the regression coefficients (or slope coefficients) are jointly significant or not and t-test allows to conclude that the regression coefficients (or slope coefficients) are individually significant or not. In this study, Adjusted R^2, F-test and t-test were jointly used to select the appropriate regression model.

Fitting with historical data set of year 2000 to 2008 of land uses as independent variables and water quality parameters as dependent variables, 13 regression models were found (Appendix I). To select the best one out of 13 regression models, first of all, they were checked with the level of significance ($p < 0.05$). Applying this concept, only 8 regression models were proposed for further purpose (Table 14). The strength of regression model can be checked through R^2 or Adjusted R^2 values and the higher values indicate the higher strength of the model. For this study, Adjusted R^2 value less than 0.2 was rejected for further process. By using this rule, only 7 regression models (TEMP, pH, DO, BOD, SS, DS and FCB) were proposed for further process.

Table 14

Regression equations of Water Quality Parameters (WQP)

WQP	Independent variables	Regression equation	R^2	Adj R^2	F-test	p-value
TEMP	URB, FOR, WTB	TEMP = 26.517 + 0.145 URB + 0.078 FOR + 0.055 WTB	0.655	0.597	11.36	0.000
pH	AGR	pH = 4.459 + 0.025 AGR	0.319	0.283	8.897	0.008
EC	AGR	EC= -157.698+ 3.0122 AGR	0.237	0.195	5.597	0.029
DO	AGR, FOR	DO= -2.337+ 0.072 AGR + 0.047 FOR	0.530	0.495	15.208	0.000
BOD	AGR, FOR	BOD= 5.535- 0.024 AGR + 0.117 URB	0.560	0.527	17.172	0.000
SS	FOR, AGR, URB	SS = -523.033+3.447 FOR + 7.662 URB + 6.555 AGR	0.568	0.424	3.948	0.047
DS	FOR, URB, WTB	DS = -6.948+5.551 FOR + 4.896 URB + 5.305 WTB	0.563	0.537	21.477	0.000
FCB	AGR, URB, WTB	FCB = 329431.478 – 3669.563 AGR-2908.470 URB – 2963.194 WTB	0.507	0.442	7.876	0.001

In this study, R^2 and Adjusted R^2 values of TEMP model ($F= 11.36$, $p< 0.05$) are 0.655 and 0.597 and the level of significance of regression coefficients of urban, forest and water body are less than 5%. Therefore, this model could be forwarded for further process. For the case of pH model ($F=8.897$, $p<0.05$), R^2 and Adjusted R^2 values are 0.319 and 0.293 and the level of significance of regression coefficient is less than 5%. This model also could be forwarded for further process. For the case of EC model ($F= 5.597$, $p< 0.05$), the adjusted R^2 is quite low (< 0.2), so it is not forwarded for further process. For the case of DO model ($F= 15.208$, $p< 0.05$), R^2 and Adjusted R^2 values are 0.530 and 0.495 and the level of significance of regression coefficients of agriculture and forest are also less than 5% level. So, this model is also forwarded for further process. For the case of BOD ($F= 17.172$, $p< 0.05$), the values of R^2 and Adjusted R^2 are 0.560 and 0.527 and the level of significance of regression coefficients of agriculture and forest are also less than 5%. So, this model is also forwarded for further process. For the case SS model ($F=3.984$, $p<0.05$), the values of R^2 and Adjusted R^2 are 0.568 and 0.428 and only the level of significance of regression coefficient of agriculture is also less than 5% level, this model is also forwarded for further process. For the case of DS model ($F= 21.477$, $p<0.05$), the values of R^2 and Adjusted R^2 are 0.563 and 0.537 and the level of significance of regression coefficients of forest, urban and water body are also less than 5% level. Therefore, this model is also forwarded for further process. For the case of FCB ($F=7.876$, $p<0.05$), R^2 and Adjusted R^2 values are 0.507 and 0.444, even only level of significance of regression coefficient of agriculture is less than 5%, this model is also forwarded for further process.

In this study, for the case of TEMP and DS, urban, forest and water body were used as predictors (Table 14). To predict pH, agricultural land use was used as predictor. For predicting DO, agricultural and forest land uses were used as predictors whereas for predicting BOD, agricultural and urban land uses were used as predictors. For SS, forest, agriculture and water body were used as predictor. For FCB, agriculture, urban and water body were used as predictors. In this study, agricultural land use appeared to have the greatest positive impact on water quality, since it showed the significant negative correlation with TEMP, BOD and SS and positive correlation with DO and it was used as a dominant predictor among land uses for pH, DO, BOD, SS, and FCB. Besides agricultural land use, urban land use was used as predictor of TEMP, BOD, DS, and FCB. Forest land use was used as predictor of TEMP, DO, SS, and DS. Water body was used as predictor of TEMP, DS, and FCB. The study demonstrated that no single land use type was able to describe the overall water quality, but most water quality variables could be sufficiently predicted using two or more than two types of land use (Table 14). From regression analysis, TEMP and DS showed sensitivity on changing urban, forest and water body whereas pH was only sensitive on changing agriculture land use. DO showed sensitivity on changing agriculture and forest land use and BOD was sensitive on changing agriculture and urban land uses. SS showed sensitivity on changing forest, agriculture and urban land use and DS showed sensitivity on changing agriculture, urban and water body.

Evaluation of regression equations

For the evaluation of regression equations, the regression equations of TEMP, pH, DO, BOD, SS, DS and FCB were selected. Generally regression equations (or models) are evaluated or validated by cross sectional method or longitudinal method. In this study, the longitudinal cross validation approach was implemented. To run the model, the set of data of 9 years (2000 to 2008) were used and to test the model, data set of 2009 were used. The graphical features of actual data (average value of 10 watersheds of year 2009) and predicted data are presented as:

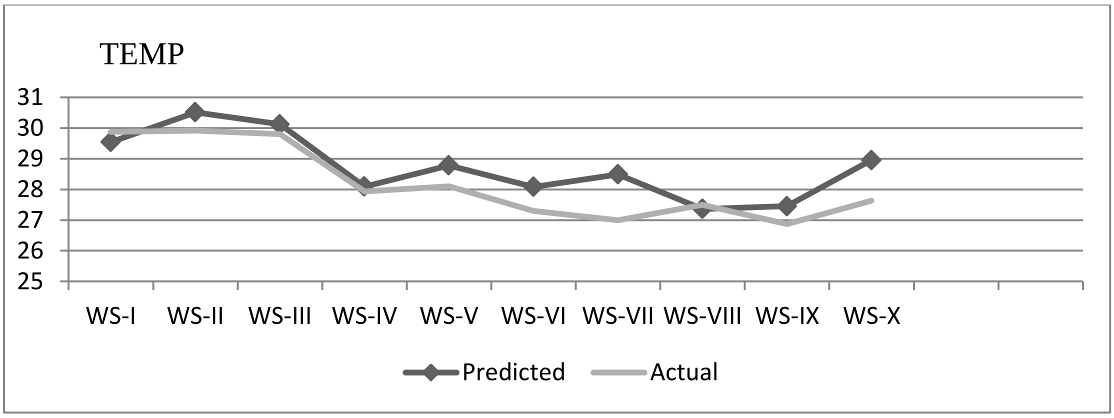


Figure 45(a). Actual and predicted values of TEMP of 10 watersheds for the year 2009

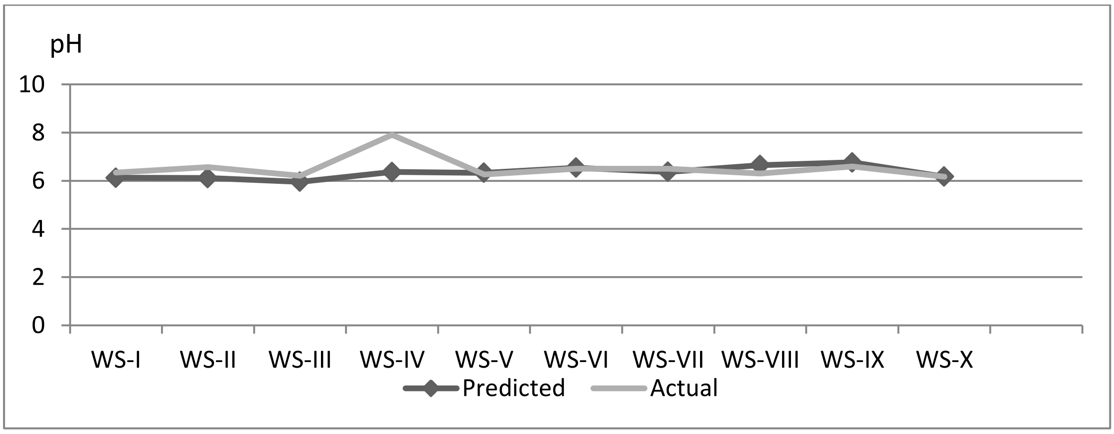


Figure 45(b). Actual and predicted values of pH of 10 watersheds for the year 2009

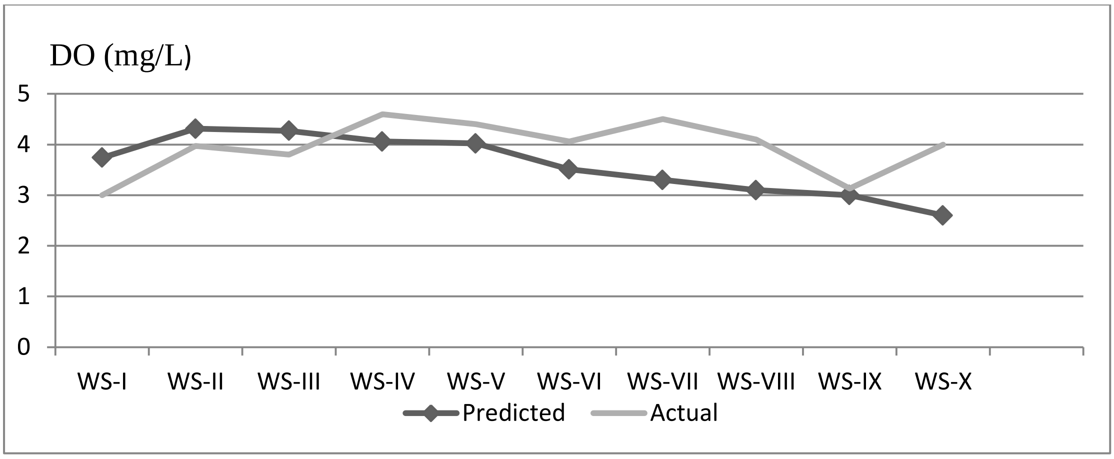


Figure 45(c). Actual and predicted values of DO of 10 watersheds for the year 2009

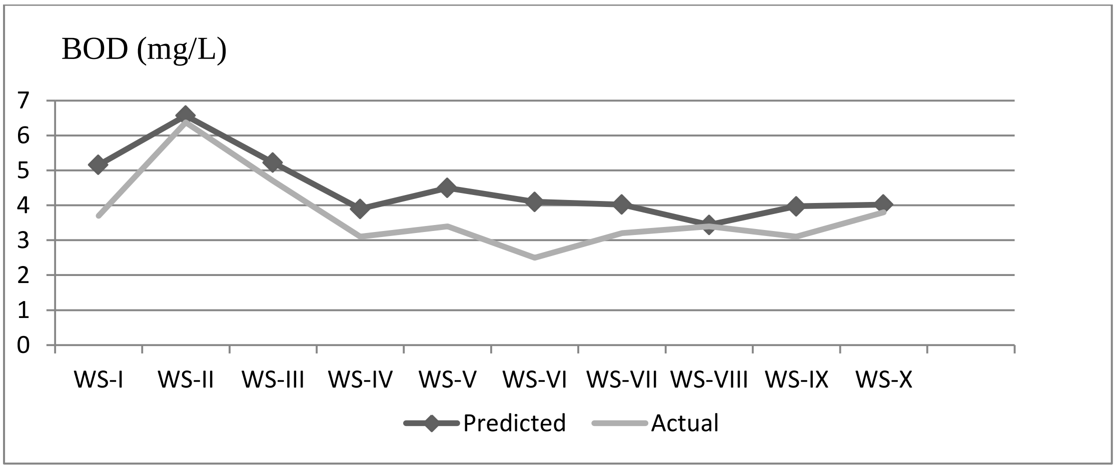


Figure 45(d). Actual and predicted values of BOD of 10 watersheds for the year 2009

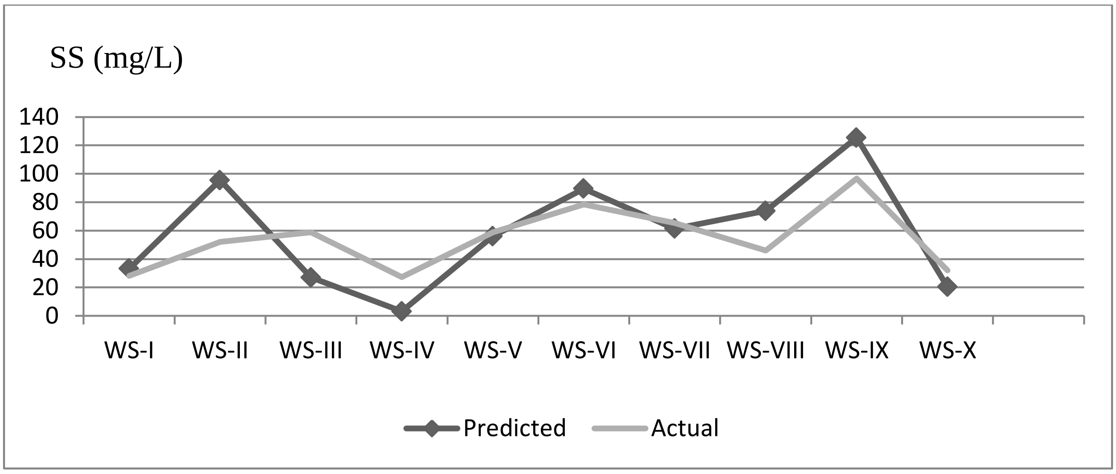


Figure 45(e). Actual and predicted values of SS of 10 watersheds for the year 2009

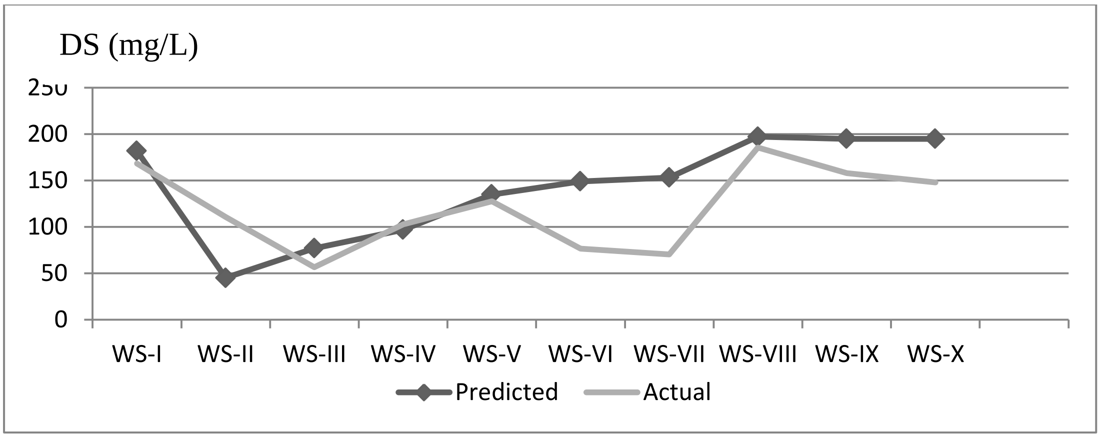


Figure 45(f). Actual and predicted values of DS of 10 watersheds for the year 2009

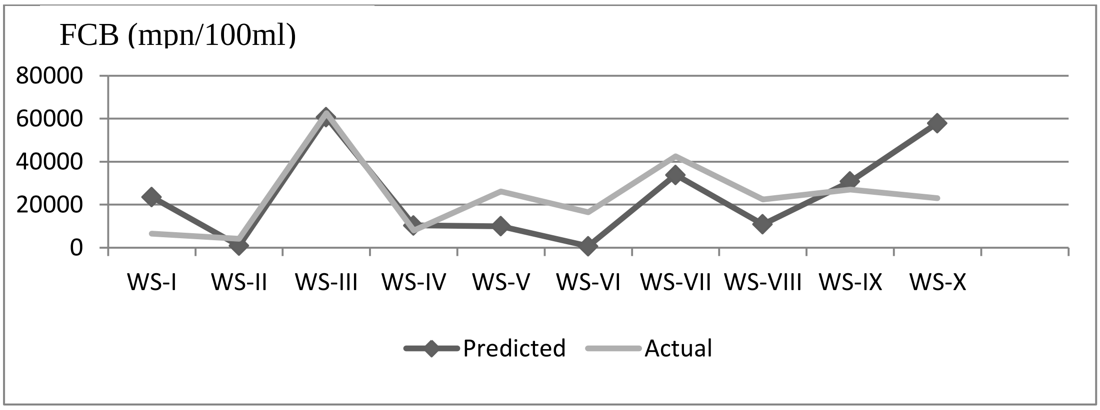


Figure 45(g) Actual and predicted values of FCB of 10 watersheds for the year 2009

From graphical ways, estimated (or predicted) curve of TEMP showed slight over estimation but there was no significant difference between predicted and actual curve. Therefore, the predicted model of TEMP could be accepted. In the case of pH, only WS-V showed over estimation, otherwise this prediction model gave satisfactory results. In the case of DO, the curve showed slightly random noise but there was no huge difference on predicted and actual curves. This curve might be accepted for further process. In the case of BOD, the predicted curve showed slight over estimation, so from the graphical analysis, BOD model could be accepted for further process. Analyzing the curves of SS, DS and FCB, it was difficult to decide whether to accept or to reject. Therefore, only analyzing the strength of models by comparing actual and predicted values from graphical ways is subjective judgment. It is better to use objective (or empirical) judgment to evaluate the regression models. For this case, average percentage of deviation (APD) method was used. In general, the lower value of APD gives the higher predictive strength whereas the larger value of APD gives the lower predictive strength of models. In this study, predictive strength of regression models is presented in Table 15 by using APD approach.

To test the regression equations developed from the first 9 years of data collection (2000-2008), the equations were applied to the tenth year of data collection (2009) to calculate estimated water quality and errors associated with these values calculating average percentage of deviation (APD). Comparatively, the APD values of TEMP, pH, DO and BOD were very low (1.14, 2.23, 1.94 and 9.2) or less than 10.0% whereas the APD of SS, DS and FCB were comparatively higher (APD>10.0%). Even though R^2 value of SS, DS, FCB are 0.56, 0.56 and 0.50 respectively the predictive models of SS, DS and FCB did not give satisfactory result by applying APD test.

Final regression models

After evaluating models by APD approach, following regression models were finally selected for predicating water quality on the basis of land use. Due to nature of regression analysis, these models can be only used for full basin as well as sub-basin of URB.

TEMP = 26.517 + 0.145 URB + 0.078 FOR + 0.055 WTB …………………………….(i)
pH = 4.459 + 0.025 AGR ……………………………………………………………….(ii)
DO= -2.337+ 0.072 AGR + 0.047 FOR …………………………………………………(iii)
BOD= 5.535- 0.024 AGR + 0.117 URB …………………………………………………(iv)

Table 15

Comparison of predicted and actual values of water quality parameters of 10 watersheds in the year 2009

Water shed	TEMP			pH			DO			BOD			SS			DS			FCB		
	Pre	Act	Res	Pre	Act	Res	Pre	Act	Res	Pre	Act	Res	Pre	Act	Res	Pre	Act	Res	Pre	Act	Res
I	29.54	29.87	-0.33	6.12	6.34	-0.22	3.00	3.13	-0.13	5.16	4.7	0.46	33.21	28.16	5.05	195.04	157.97	37.07	23519	6437	17082
II	30.51	29.91	0.6	6.11	6.57	-0.46	2.6	4.0	-1.4	6.57	6.37	0.2	95.43	52.09	43.34	195.04	147.88	47.16	888	4093	-3205
III	30.12	29.80	0.32	5.96	6.20	-0.24	3.1	4.1	-1.0	5.22	4.7	0.52	27.01	58.88	-31.87	197.14	185.51	11.63	60619	62480	-1861
IV	28.09	27.93	0.16	6.36	7.90	-1.54	3.30	4.5	-1.2	3.9	3.5	0.4	3.07	27.34	-24.27	153.25	70.5	82.75	10343	7980	2363
V	28.78	28.10	0.68	6.33	6.26	0.07	3.51	4.06	-0.55	4.5	3.4	1.1	56.04	58.8	-2.76	149.08	76.5	72.58	9911	26056	-16145
VI	28.08	27.30	0.78	6.54	6.50	0.04	4.06	4.6	-0.54	4.1	3.8	0.3	89.47	78.5	10.97	97.06	102.67	-5.61	679	16508	-15829
VII	28.49	27.00	1.49	6.37	6.50	-0.13	4.02	4.4	-0.38	4.02	3.4	0.82	61.33	65.34	-4.01	134.28	127.51	6.77	33833	42495	-8662
VIII	27.36	27.50	-0.14	6.65	6.30	0.35	4.27	3.8	0.47	3.44	3.4	0.04	73.79	45.9	27.89	76.99	56.6	20.39	10851	22401	-11550
IX	27.45	26.87	0.58	6.76	6.59	0.17	4.31	3.97	0.34	3.97	3.3	0.67	125.41	96.6	28.81	45.06	110.87	-65.81	30745	27076	3669
X	28.95	27.63	1.32	6.17	6.16	0.01	3.74	3.0	0.74	4.02	3.8	0.2	20.36	32.0	-11.64	181.92	168.34	13.58	57870	23050	34820
Avg	28.73	28.08	0.64	6.33	6.53	-0.19	3.59	3.95	-0.36	4.49	3.54	.94	58.51	54.36	4.15	142.49	120.44	22.05	23926	23858	68
SD	1.06	1.30	0.77	0.25	0.50	0.52	0.58	0.53	0.72	0.92	1.19	0.55	38.30	22.41	24.09	53.89	44.28	42.15	21772	17817	15834
APD=1/n√$(Res/Act)^2$ *100			1.14			2.23			1.94			9.2			15.56			17.14			34.14

Note: Pre: Predicted, Act: Actual, and Res: Residual

Discussion

Over the last ten years, a combination of different factors affected the water quality of U-tapao river and turned it into a moderately polluted river. Among the factors that polluted the river, the most important ones are: rapid, unplanned urban and industrial expansions; domestic and industrial waste discharge into the river and other non-point sources such as run-off from streets and highways. Generally, pollutants that enter surface waters from a pipe or other man-made conveyance are classified as PS pollutants (e.g. industrial or water treatment plant discharge). In contrast, non-point sources (NPS) pollution enters the water system through diffuse sources including percolation through land and soil cover and through storm runoff. Controlling point sources of pollution is relatively easy, and many of the early water pollution programs focused on reducing the pollution load from point sources. In the case of non-point source pollution, awareness program on environmental issues, public participatory approach, and promotion of appropriate management practices and modification of land use are among the methods that reduce the non-point source pollution.

Analyzing the water quality data from various monitoring stations, U-tapao river could be categorized as the moderately polluted river. The reason being that the average water temperature of river was around 28.72 ^{0}C and standard deviation was just 1.73 ^{0}C and the range was between is 25 ^{0}C to 35 ^{0}C which indicates the water temperature does not fluctuate too much. In the case of pH, average value was 6.82 and SD was 0.19. Even though average value of pH showed slightly acidic character, it was within the range of 6.0 to 8.0 which is within acceptable limit for natural river or lake. The mean and SD of DO were 4.16 mg/L and 1.49 mg/L respectively and the mean and SD of BOD were 3.37 mg/L and 2.39 mg/L respectively. In this study, data of BOD and DO showed the consistency performance. In the case of DO, most of data are within the range between 2 mg/L to 6 mg/L and similarly for BOD, most of the data were also within the range between 2 mg/L to 6 mg/L. This range of BOD and DO indicated slightly polluted river system. The mean and SD of TCB of river were 41,274 mpn/100ml and 241,270 mpn/100ml respectively. The mean and SD of FCB of river were 17,251 mpn/100ml and 49,254 mpn/100ml respectively. In the river system, the amount of these fecal coliform bacteria was quite high, so without treatment it is not possible to use for domestic purpose. Comparing the average values of water quality parameters with Thailand surface water quality framework, the river system can be categorized as slightly polluted river. Therefore, the water quality standard of U-tapao river is not yet out of control. Therefore, by effective water quality management, the water quality of U-tapao river could be improved.

Analyzing the seasonal pattern of several water quality parameters, only limited water quality parameters (TEMP, pH, TUR, NH_3 and FCB) showed significant seasonal variation. It indicates that natural process of declining of water quality could not be linked in U-tapao case (Singh et al., 2004; Pejman et al., 2009). Analyzing the trend pattern of water quality parameters of river from the year 2001 to 2011, the water quality status has been slightly decreasing with change in time. In this study TEMP, BOD, TUR and NH_3 showed the rising trend lines whereas pH and EC showed declining trend lines. These results indicated that river water quality has been deteriorating due to anthropogenic activities and necessary steps should be taken to stop further deterioration.

Analyzing the spatial and annual variations of water quality parameters of river, TEMP and DO showed significant variation on spatial level ($p < 0.05$) where as pH, BOD, EC, TUR and NH_3 showed only significant variation on annual level ($p < 0.05$). Such variations could be attributed to the increased input of industrial effluents from the local industries sited along the bank of the river, leached domestic wastes from the several waste dumps, erosion and surface run-offs and other human activities along downstream of the river (Najafpour et al., 2008; Adamu & Nabegu, 2011). In the case of seasonal variation, only TEMP, pH, TUR, FCB and NH_3 showed significant variation ($p<0.05$). Generally, seasonal variation happens due to natural process whereas annual spatial variation happens due to anthropogenic activities (Shrestha and Kazama, 2007). Including all types of variations, TEMP was the most sensitive parameter for variation analysis. So, this type of understanding of variations of water quality parameters helps to select appropriate parameters for effective evaluation and monitoring system of river. In the case of variations analysis of water quality parameters, previous studies included only spatial and seasonal variations for analysis of water quality parameters (Ojutiku & Kolo, 2011). Excluding annual variation might give misleading information about variation of water quality parameters. Comparing the annual and spatial variation, most of the parameters showed variation on annual level rather than on spatial level. In this study, the values of TEMP, BOD, EC, TUR and NH_3 of downstream region were quite higher than that of upstream region, and the values of DO of downstream region were quite lower than that of upstream region (Figure 5.16, 5.18, 5.19, 5.20, 5.21, 5.23). The changing land use pattern on upstream region and urbanization effect of downstream region are the main causes of increasing pollutant values in downstream region. Therefore, it is necessary to adjust effective land use policy of the basin to improve water quality of the river (Ferrier et al., 1995).

For effective land use planning, the basic information of land use and changing patterns of land use are very important, because land uses are recognized as a result of interactions between biophysical and socio-economic aspects of human activities (Saroinsong et al., 2007; Lambin et al., 2000). It has been regarded as one of the most important driving forces in global environmental changes, and is essential in the debate of sustainable development (Lambin et al., 2000; Lesper et al., 2005). Therefore, land use is intensively used as a proxy to evaluate the effects of human activities.In the case of U-tapao river basin, no studies have ever been done by changing land use pattern of the basin. Analyzing the land use structure of the basin from year 2000 to 2009, agriculture is the dominating land use of the overall of the basin and it covered area about 1847.68 km^2 (80.16%) in year 2000 but it was decreased to 1696.71 km^2(73.61%) in year 2009. In agriculture sector, rubber is the most dominating land use but it also decreased significantly from year 2000 to 2009. Surprisingly, other land uses like forest, urban and water body have been increasing in significant manner from year 2000 to 2009. From land use management aspect, there is no problem of deforestation in U-tapao river basin but conversion of agricultural land to urban land is a major issue of sustainable development of river basin. In the conclusion, in the basin, agriculture, especially rubber plantation, is the main economic activity of the basin. But nowadays, it has been decreasing and this pattern might create obstacle on economic development of the basin in the future. In the last decade, urban area of the basin has grown in a significant manner. The basic objective of urban development is to promote urban activities and play supportive role in economic development. During the last decade, the transportation network has increased rapidly and supported housing development and expansion of settlements in the basin. There was significant negative correlation between agriculture and urban land which indicates the urbanization process of the basin.

Many studies demonstrated that surface water quality has degraded noticeably in many parts of the world due to poor land use practice and there is significant relationship exist between water quality parameters and land use types (Li.et al., 2009, Zampella et al., 2007, Tu, 2011; Azyana & Norulaini, 2012; Sliva & Williams, 2001; Basnyat et al., 1999). In the case of study U-tapao river, the water quality of river has been affecting from point sources as well as nonpoint sources pollution and it is believed that one of the main causes of nonpoint sources of land use structure and their changes in the basin level. For instance, TEMP had significant negative correlation with agriculture and positive correlation with urban, forest, and water body. Surprisingly, agricultural land use negatively correlated with TEMP while forest and urban body were positively correlated with TEMP. BOD had significant negative correlation with agriculture and positive correlation with urban and water body. DO had significant positive correlation with agriculture and negative correlation urban and water body. These results suggest that local urban land cover and vegetation extent could be the primary driving forces behind the variations in DO and TEMP. Similarly, DS had significant negative correlation with agriculture and positive correlation with forest, urban and water body. SS had significant negative correlation with agriculture and positive correlation with urban land use. Since surface water contamination is highly dependent on storm water runoff, it is not surprising that contaminants located in urban land use are more likely to reach water bodies. It was observed during field surveys that the urban sites in this study had very little or no vegetated riparian zone, therefore increasing the probability that concentrations of these contaminants increased after storm events. Runoff from agricultural land and effluents from urban and industrial areas are major sources of fine sediment in river systems (Rothwell, 2010). The results indicate that mean concentrations of solid particles are most strongly linked to urban cover, suggesting that anthropogenic sources are the major contributor to fine sediment delivery in the basin (Rothwell, 2010).

Analyzing non-point source pollution, agricultural and urban lands were usually related to be the causes of poor water quality. In contrast, in U-tapao river basin, the agricultural land did not show any positive relationship with increment of pollutants and it is used as protector of water quality of river. For example, agricultural land use showed negative correlation with TEMP, BOD and DS and positive correlation with DO but urban land showed the opposite result, positive correlation with TEMP, BOD, and DS and negative correlation with DO. This suggests that urbanization is a major factor that has led to the decrease of agriculture as well as deteriorating water quality of river. It is clearly explained that the main culprit of deteriorating water quality is changing pattern of agricultural land to urban land which has the potential to generate large amount of non point source pollution from storm water discharge (Basnyat et al., 1999). The dominating land use of the basin is agricultural based rubber, and farmers do not use excess amount of nutrients and fertilizers like traditional agricultural practices, and these lands are not open for surface runoff. This might be the reason that agriculture does not act as the source of pollution in the river. In the basin, agricultural land was decreasing whereas urban land was increasing; therefore, agricultural land was not associated with deteriorating water quality in this area. Urban areas are primarily located along the river networks in the U-tapao River basin, and their impacts on the water quality in streams were expected. This result also suggests that urban sprawl related to the increasing residential, commercial, and industrial lands, and population density in suburbs was an important cause of water quality degradation in the study area. It is clear that this relationship may have been highly influenced by the pollution from point sources as well as non-point sources, which are commonly associated with urbanized areas. Another factor that also appeared important in this study is to determine the water quality changes to the extent of forest coverage. In general, undisturbed forest land has little impact on water quality. In this study, forest land had positive correlation with TEMP and DS and negative correlation with NO_2. Most of forest land in the basin is far from the river and there is no forest land lies in riparian zone. Overall increment of forest land was just 0.23% which acted like passive land use for water quality variation.

It is therefore conceivable that there is a strong relationship between land-use types and the quality of water, and changing land use is therefore regarded as one of the main factors in altering water quality (Tong & Chen, 2002). The results showed that, unequivocally, land use was related to many water quality parameters. Due to the relationship between pollution loading and composition of the land uses in the river basin, there is always potential for improving water quality with proper land use management practices, if the role of different land use combinations within a contributing area is known (Basnyat et al., 1999). To address these problems, the predictive water quality models based on land use patterns can be implemented in watershed or basin level. In the study, by implementing stepwise multiple linear regressions, it was found that no single land use type was sufficient to describe the overall water quality, but most water quality variables could be sufficiently predicted using two or more than two types of land use. In this study; urban, forest and water body were used as predictors for TEMP, agriculture was used as predictor for pH, agriculture and forest were used as predictors for DO and agricultural and urban land were used as predictors for BOD. All of the simulated values were very close to the actual monitored values. It seems likely that with little calibration and validation, the models can be used to other watersheds or basins (Tong & Chen, 2002).

CHAPTER 6

RESEARCH METHODOLOGY - II

Land suitability

This chapter mainly focuses on the study of land use planning on the basis of land suitability principle in U-tapao river basin. Despite the fact that land suitability analysis is crucial part for decision makers, conflict between different stakeholders makes it complex. Although land suitability assessment has become a standard practice in land use planning, due to the difficulties encountered with the analysis of large amounts of spatial information, decision makers are often unable to allocate the most suitable areas to allocate limited land resources. The objective of this part is to present a GIS-based systematic approach incorporating multi-criteria mechanism for land suitability analysis. This study incorporated the use of multi-criteria mechanism with analytical hierarchical process in a Geographic Information Systems (GIS) for the evaluation of the suitability of areas for three possible land-uses: Forest, Agriculture, and Urban (Son & Shrestha, 2008).

Software used

Following software were used for analyzing the variables used in this study:

1) MS word was used to make adjust information and process of land use suitability analysis.

2) MS Excel 2007 was used to create the attribute databases and import or export to GIS environment for next implementation, for multi-criteria analysis,

(weighting, rating) based on Analytical Hierarchy Process as theory put forward by Saaty (1980).

3) Arc GIS 9.0 was used to make analysis of all the GIS work in the thematic layers of the study area map.

4) ERDAS was used just to make visualization of satellite images. Such images were used to check real time land use changes in the study area and make necessary amendments on the thematic layers.

Geographic Information Systems (GIS) application

In land use suitability analysis, Geographic Information Systems (GIS) is very commonly used software. In this study, ArcGIS from ESRI were used as a tool for the GIS analysis with integrating Multi Criteria Decision Making (MCDM) approach. Basically, the map overlay approach; one of analytical tools of GIS has been used in suitability analysis in the form of weighted linear combination (WLC). The primary of reason of this approach is that it is easy to implement within the GIS environment using map algebra operations. Most GIS systems are database oriented. GIS-based MCDA can be thought of as a process that combines and transforms spatial and non-spatial data (input) into a resultant decision (output) (Ceballos & Lopez, 2003). The MCDM procedures (or decision rules) define the relationship between the input maps and the output map. The procedures involve the utilization of geographical data, the decision maker’s preferences and the manipulation of the data and preferences according to specified decision rules. Accordingly, two considerations are critical importance for spatial MCDA: (i) the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis, and (ii) the MCDM capabilities for combining the geographical data and the decision maker's preferences and non-spatial attributive data into one-Dimensional values of alternative decisions (Jankowski et al., 2000; Malcewski, 2006)

Data sources and collection

The success of any GIS based land use suitability depends on the quality of the geographic data used (Lo & Yeung, 2002). Collecting high quality data for input for GIS, therefore, marks a critical stage. Data collection is one of the most important parts of GIS-base analysis and GIS can contain a wide variety of data from various sources. To achieve the above objectives of this study, both primary and secondary data were used.

Secondary Data

Soil: Soil data like depth, drainage, texture, nutrient, and pH were collected and managed through the soil series map of Songkhla Province provided by Land Development Department, Southern Thailand (1:50,000).

Climate: Rainfall and temperature are the major climatic factors influencing the land use suitability. Climate data like rainfall, temperature, humidity and wind speed were collected and managed through the data provided by Metrological Centre, Hatyai, Thailand.

Topography: Topography features like slope and elevation were generated through digital elevation modeling (DEM) on 25m resolution process by using the DEM map provided by GEO-IRCNRE.

Land use: Land use information like the area of agriculture, forest, urban, water body etc. were derived from GIS environment by using the land use map provided by Land Development Department, Thailand and GEO-IRCNRE.

Socio-economic: The socio-economic data like demographic, political features, economic status etc were retrieved from the reports of GEO-IRCNRE.

Primary Data

Primary data were accomplished by in-depth interview with experts which are one of the important social research methodologies. It was used to identify problem in the study area and to set up priority of the requirement. Formal and informal interviews, group discussions were also conducted to gather information. Seminars and meetings conducted with experts, officials, and policy makers were also used to make assessment.

Thematic maps

Thematic maps are the basis of the suitability analysis. The maps in the present study include land use maps, soil maps, climate maps, DEM maps and map of administrative boundaries. Those thematic maps were created and edited, overlaid and visualized by GIS software.

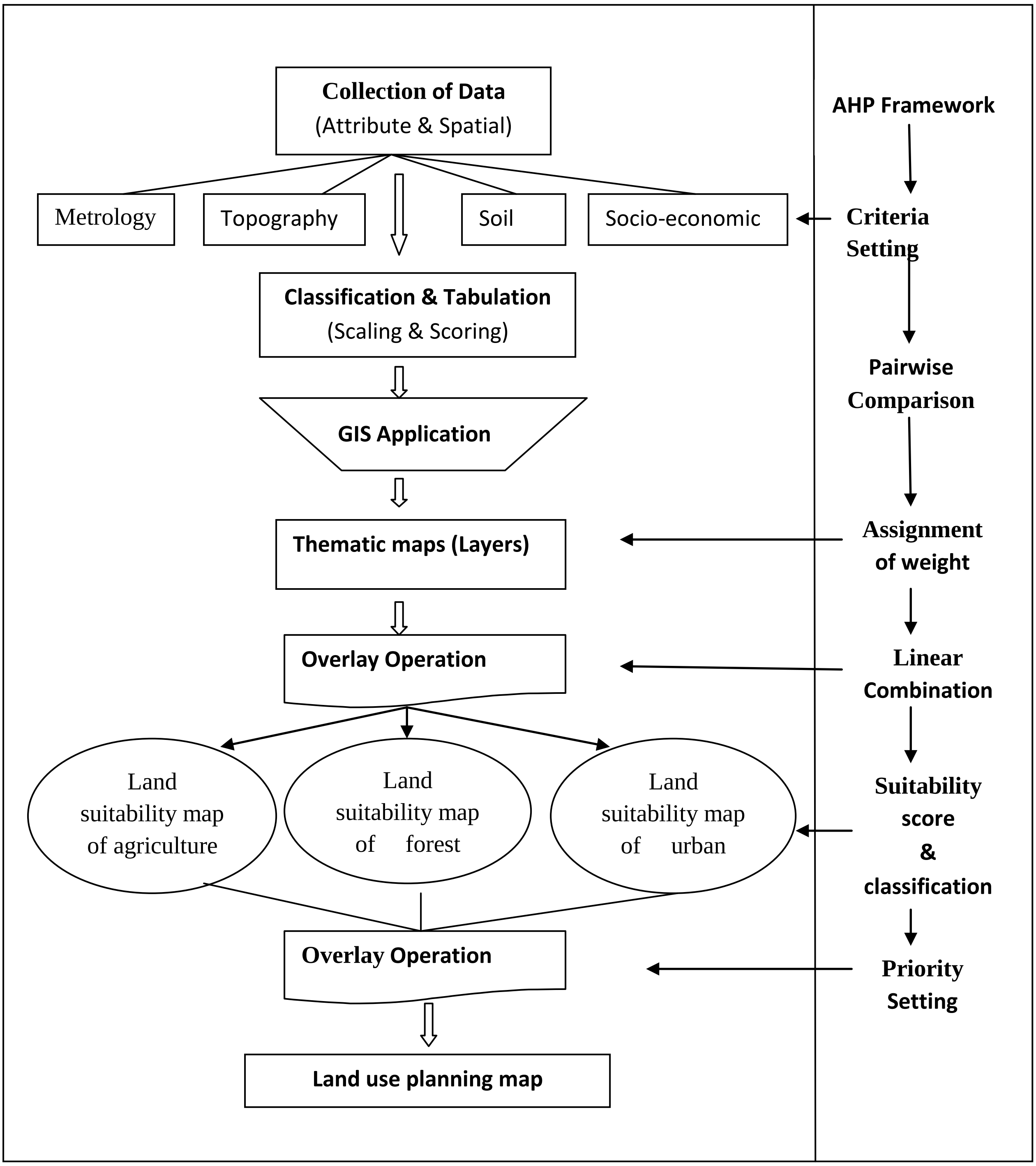


Figure 46. Research Methodology-II Framework

Methods and Tools

Decision supporting tool, GIS based, Multi Criteria Decision Making (MCDM) were used to find suitable land structure of basin for allocated land use pattern. The integration of multi-criteria methods and GIS allows overcoming this limitation and provides a tool with great potential for obtaining land suitability maps or selecting sites for a particular activity. GIS is also very powerful tool for collecting, storing, retrieving, transforming, displaying spatial data from the real world for a particular set of purposes (Ceballos & Lopez, 2003; Boonyanuphap et al, 2004).

Land suitability analysis

Land suitability analysis is an evaluation/decision of a problem involving several factors. The parameters considered for land suitability analysis are: topography, climate, soil, livelihood and distance. Each criteria map displays land suitability measured on the ordinal scale, that is, parcels of land were assigned values of high, moderate or low suitability depending on land attributes. The criteria maps were the input data to the GIS based decision procedure. Given these maps, the next step was to combine the maps so that one can identify the suitable areas for land uses. There were three crucial steps to produce land suitability map for each chosen land use; (1) finding suitable factors to be used in the analysis, (2) assigning factor weight and class weight (rating) to the parameters involved, and (3) formulating land suitability map for each interested land (Ceballos & Lopez, 2003; Boonyanuphap et al, 2004).

Selection of Evaluation Criteria

There are large numbers of criteria for land use suitability, but only those relevant to land use alternatives under consideration need be determined. Identification of criteria is a technical activity, which is based on theory, empirical research or common sense. Evaluation criteria, objectives and attributes, should be identified with respect to the problem situation. A set of criteria selected should adequately represent the decision making environment and must contribute towards the final goal and criteria should be measurable on the basis of land quality. After the determination of the problem, the set of evaluation criteria which includes attributes and objectives should be designed. This stage involves specifying a comprehensive set of objectives that reflects all concerns relevant to the decision problem and measures for achieving those objectives which are defined as attributes because the evaluation criteria are related to geographical entities and the relationships between them, can be represented in the form of maps which are referred as attributes maps (Paiboonsak et al., 2004). In this study, identification of criteria for agriculture (rubber) was done through literature review of FAO guidelines (Ranst et al., 1996). FAO (1976) has given a framework for land suitability analysis for crops in terms of suitability classes from highly suitable to not suitable based on the crop specific, soil, climate and topographic data. Besides this, opinions from rubber experts from different fields were also incorporated for criteria selection. Identification of criteria for forest and urban land uses were done through in-depth survey of literature of related field as well as experts’ opinion from forestry and urban sectors (Jian et al., 2008; Park et al., 2011; Rashim et al., 2011).

Table 16

Criteria and sub-criteria of land suitability of agriculture, forest and urban

Main criteria	Sub criteria	Agriculture	Forest	Urban
Bio-physical	Topography	Slope	Slope	Slope
		Elevation	Elevation	Elevation
	Climate	Rainfall	Rainfall	Rainfall
		Temperature	Temperature	Temperature
	Soil	Texture	Texture	Texture
		Drainage	Drainage	Drainage
		Depth	Depth	Depth
		Nutrient	Nutrient	
		pH	pH	
Socio-economic	Livelihood	Population density	Population density	Population density
		Available land use	Available land use	Available land use
	Distance	Distance from road	Distance from road	Distance from road
		Distance from factory		
			Distance from river	Distance from river

After identification of suitable criteria for agriculture, forest and urban land use, they were divided into two main categories: bio-physical and socio-economic sections. Bio-physical factor (category) was further sub-divided into three sections: climate (rainfall & temperature), topography (slope & elevation) and soil (drainage, pH, depth, texture and nutrient). Socio-economic factor is also sub-divided into two sections: livelihood (land use & population density) and distance (river, road and factory).

Hierarchical Organization of the Criteria

The relationship between objectives and attributes can be demonstrated in a hierarchical structure. At the highest level, one can distinguish the objectives and at the lower levels, the attributes can be decomposed. Figure 47 below shows the hierarchical organization of the criteria used in this study.

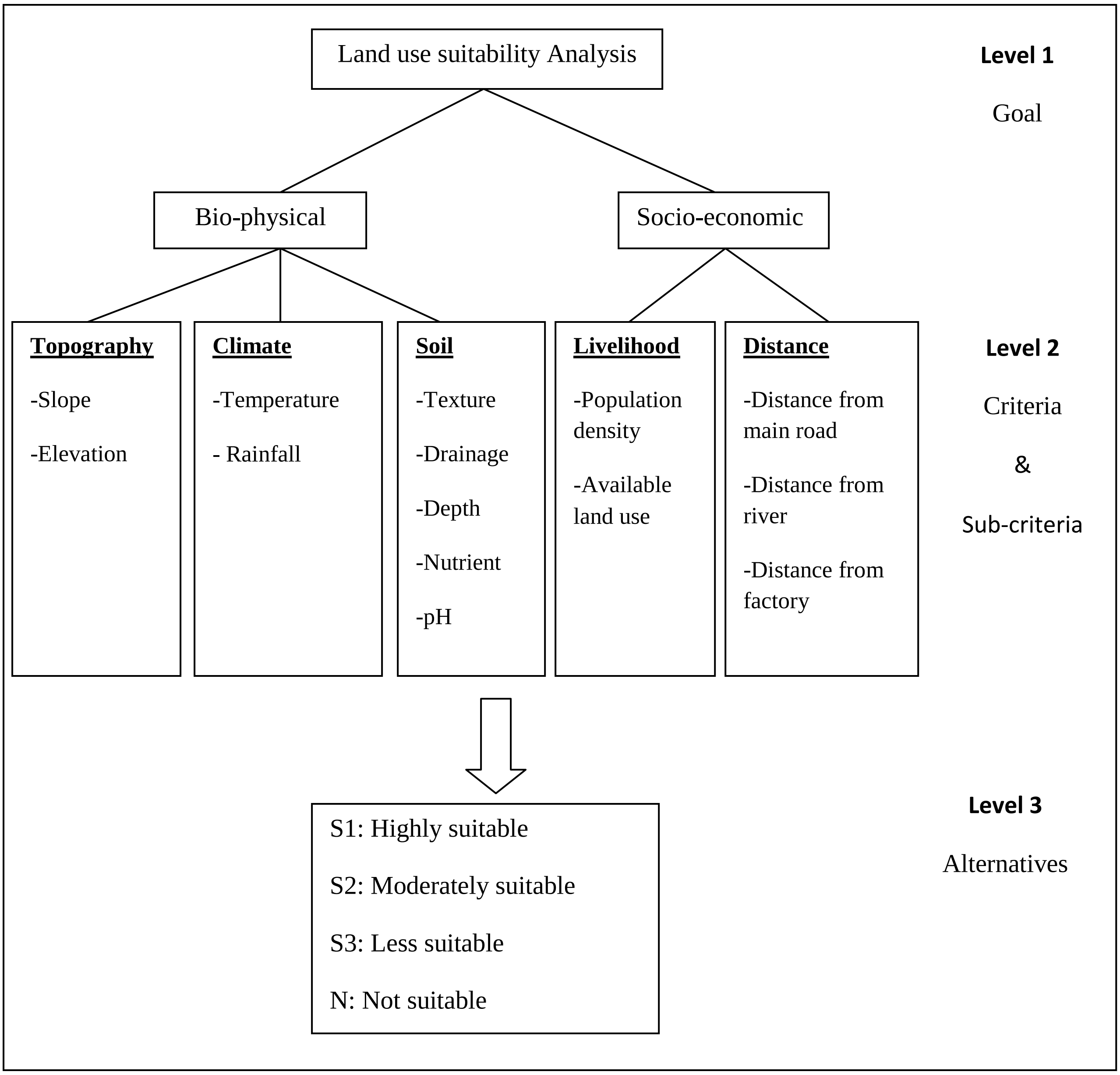


Figure 47. Hierarchical structure of land use suitability analysis

Factor/Criteria Rating

Land suitability analysis for land needs the consideration of different socio-economic and environmental factors/criteria (Ceballos-Silva & Lopez Blanco, 2003). In this study, land suitability analysis criteria were mainly related topography, climate, soil, livelihood and distance. Soil data were assessed in terms of its depth, drainage, texture, nutrient and pH. Rainfall and temperature were taken as climate factors. These are the most important requirements needed for all lands. Factor ratings were sets of values which indicate how well each factor/criterion is satisfied by particular conditions of the corresponding land quality. Factor ratings are usually made in terms of five classes: highly suitable, moderate suitable, marginally suitable, and currently not suitable and permanently not suitable (FAO, 1985; 1993). But in this study, only four criteria: highly suitable, moderately suitable, less suitable and not suitable were mentioned. On establishing the criteria rating (Table 17, 18, 19), references were made to: guidelines of FAO, research publications, and relevant literature. In addition experts from different disciplines like soil scientists, agriculturists, forest officers and land use planners from different disciplines were consulted in arriving at a factor rating of given land use type that can be used in the matching process. After criteria rating, criteria standardization is also an important part for land use suitability analysis. Generally, criteria standardization is done on 0 to 1 scale, but in this study 1 to 4 scale was used. So, all the factors used for this study were classified into four classes (S1, S2, S3 and N) with the range of values 4 to 1, where the value of 4 denotes the most suitable and 1 denotes the least suitable for all factors considered. Following table indicates factors and rating of agriculture (rubber), forest and urban land use.

Table 17

Factors and rating of land use suitability of rubber (agriculture)

Factor	Land use requirement			Factor rating			
	Land quality	Factor	Unit	S1 (4)	S2 (3)	S3 (2)	N (1)
Bio-physical	Climate	Temperature	^{0}C	26-28	29-34, 23-25	20-22	>34, <20
		Rainfall	mm	1500-2000	2500-4500 1200-1500	4500-5000 1100-1200	>5000 <1100
	Topography	Slope	Degree	0-12	12-20	20-35	>35
		Elevation	m	0-200	200-400	400-600	>600
	Soil	pH	pH	5.1-7.3	7.4-8.0 4.0-5.0	3.5-3.9	>8.0 <3.5
		Drainage	class	Well drained/ Excessively drained	Moderately well drained	Somewhat poorly drained	Poorly drained Very poorly drained
		Depth	cm	>150	50-150	30-50	<30
		Nutrient	class	Very high/ high/Moderate	Low	-	-
		Texture	type	sic, sicl, l, scl, sil, si, cl	sl	ls	c, g, sc, s
Socio-economic	Distance	Main road	km	<1	1-5	5-10	>10
		Rubber factory	km	<10	10-15	15-20	>20
	Livelihood	Population density	n/km^2	<100	100-300	300-500	>500
		land use	type	Agriculture	Grass, shrub	Forest	Urban, water body

Source: FAO (1983); Surajit et al. (2010); Mongkolswat et al. (2010); Ransat et a. (1996); Kanalaya et al. (2009); Baniya (2008)

Table 18

Factors and rating of land use suitability of forest

Factor	Land use requirement			Factor rating			
	Land quality	Factor	Unit	S1 (4)	S2 (3)	S3 (2)	N (1)
Bio-physical	Climate	Temperature	^{0}C	24-28	28-30	30-32	>32,<24
		Rainfall	mm	>2000	1500-2000	1000-1500	<1000
	Topography	Slope	Degree	0-12	12-20	20-35	>35
		Elevation	m	<400	400-600	600-1000	>1000
	Soil	pH value	pH	5-6	6-7, 4-5	7-8, 3-4	<3, >8
		Drainage	class	Well drained/ Excessively drained	Moderately well drained	Somewhat poorly drained	Poorly or very poorly drained
		Depth	cm	>150	100-150	50-100	<50
		Nutrient	class	Very high/ high	Moderate/ Low	-	-
		Texture	type	l, scl, sl	ls, sil, sc, cl, sicl	si , sic, sc,	c, g, ac, s
Socio-economic	Distance	Main road	km	>5	4-5	3-4	<3
		River	m	<500	500-1000	1000-2000	>2000
	Livelihood	Population density	n/km2	<100	100-300	300-500	>500
		land use	type	Forest	Grass, shrub	Agriculture	Urban, water body

Source: Nguyen Van Loi (2008); Sasan et al. (2009); Orhan et al. (2010)

Table 19

Factors and rating of land use suitability of urban

Factor	Land use requirement			Factor rating			
	Land quality	Factor	Unit	S1	S2	S3	N
Bio-physical	Climate	Temperature	^0C	20-25	15-20, 25-30	10-15, 30-35	<10, >35
		Rainfall	mm	500-1000	1000-1500	1500-2000	<500 >2000
	Topography	Slope	Degree	<12	12-20	20-35	>35
		Elevation	m	0-200	200-400	400-600	>600
	Soil	Drainage	class	Well drained / Excessively drained	Moderately well drained	Somewhat poorly drained	Poorly or very poorly drained
		Depth	cm	>150	100-150	50-100	<50
		Texture	type	sandy	loamy	clayey	rocky, stone
Socio-economic	Distance	Main road	km	<1	1-5	5-10	>10
		River	m	>2000	1000-2000	500-1000	<500
	Livelihood	Population density	n/km^2	>500	300-500	100-300	<100
		Land use	type	Urban	Grass& shrub	Agriculture	Forest, Water body

Source: Yao Mu (2006); Kai et al. (2011); Park et al. (2011); Dai et al. (2001); Tudes (2011)

Assigning Criterion Weights

In order to produce land suitability map, actual factor weight and class rating for parameters involved in the study are needed. These were determined systematically based on the Analytic Hierarchical Process (AHP) which is one of the most well-known and widely-used MCDM methods (Bennai al., 2007). AHP was developed by Saaty (1980) and it has become a widely used multi-criteria evaluation method later on.

AHP assists the decision-makers in simplifying the decision problems by creating a hierarchy of decision criteria with different number of factors taken into account in each step. The method is usually implemented using the pair-wise comparison technique that simplifies preference ratings among decision criteria. In most studies, expert opinions were used to calculate the relative importance of the involved factors (or criteria). In this study also, opinion from 30 experts from different fields (agriculture, forest and urban) were used for pair wise comparison technique for AHP.

On this process, the first step of the analysis was to create questionnaires where experts were asked to determine the relative importance of each given factor when compared other. Results of the comparison (for each factor pair) were described in terms of integer values from 1 to 9 where higher number means the chosen factor is considered more important in greater degree than other factor being compared with (Table 20). The purpose of weighing in land suitability analysis for land use is to express the importance or preference of each factor relative to other factor effects. So, the weights of factors and variables were determined depending on the importance of each factor and variable. The greater the weight, the larger the value and the more important the decision factor and variable would be. In the procedure for MCE, it is necessary that the weights sum to 1. By using the pairwise comparison technique, it helps to develop a set of factor weights that will sum to 1.0. However, to ensure the credibility of the output weights, the consistency ratio index (CR) for each land was also calculated. Saaty (1980) suggested that if CR is smaller than 0.10 then degree of consistency is fairly acceptable. But if it is larger than 0.10 then there are inconsistencies in the evaluation process, and AHP method may not yield meaningful results.

Table 20
Preference scale for pairwise comparison in AHP technique

Scale	Degree of preference	Explanation
1	Equally	Two activities contribute equally to the objective
3	Moderately	Experience and judgment slightly to moderately favor one activity over another
5	Strongly	Experience and judgment strongly or essentially favor one activity over another
7	Very strongly	An activity is strongly favored over another and its dominance is showed in practice
9	Extremely	The evidence of favoring one activity over another is of the highest degree possible of an affirmation
2,4,6,8	Intermediate values	Used to represent compromises between the preference in weights 1, 3, 5, 7 and 9
Reciprocals	Opposites	Used for inverse comparison

Source: Saaty, 1980

By using pairwise comparison technique in AHP, the weight of factor (or criteria) of agriculture (rubber), forest and urban were developed. The following tables give the detail.

Table 21

Weight of factors for land use suitability analysis of rubber (agriculture)

Factor						
Level 1	Weight 1 (w1)	Level 2	Weight 2 (w2)	Level 3	Weight 3 (w3)	Total (w1*w2*w3)
Bio-physical	0.916	Topography	0.270	Slope	0.750	0.1855
				Elevation	0.250	0.0618
		Soil	0.150	Drainage	0.148	0.0203
				pH	0.168	0.0230
				Depth	0.287	0.0394
				Nutrient	0.029	0.0039
				Texture	0.366	0.0502
		Climate	0.580	Rainfall	0.580	0.3081
		Total	1.000	Temperature	0.420	0.2231
Socio-economic	0.084	Livelihood	0.416	Population density	0.416	0.0145
				Available land use	0.584	0.0204
		Distance	0.584	Distance from road	0.580	0.0284
				Distance from factory	0.420	0.0206
Total	1.000	Total	1.000	Total		1.0000

Table 22

Weight of factors of land use suitability analysis of forest

Factor						
Level 1	Weight1 (w1)	Level 2	Weight2 (w2)	Level 3	Weight3 (w3)	Total (w1*w2*w3)
Bio-physical	0.750	Topography	0.3940	Slope	0.7500	0.2216
				Elevation	0.2500	0.0739
		Soil	0.1515	Drainage	0.2815	0.0319
				pH	0.1067	0.0122
				Depth	0.2718	0.0309
				Nutrient	0.0488	0.0055
				Texture	0.2912	0.0331
		Climate	0.4545	Rainfall	0.5800	0.1977
		Total	1.0000	Temperature	0.4200	0.1433
Socio-economic	0.250	Livelihood	0.5834	Population density	0.4160	0.0607
				Available land use	0.5840	0.0851
		Distance	0.4166	Distance from road	0.3400	0.0354
				Distance from river	0.6600	0.0687
Total	1.000	Total	1.0000	Total		1.0000

Table 23

Weight of factors of land use suitability of urban

Factor						
Level 1	Weight1 (w1)	Level 2	Weight2 (w2)	Level 3	Weight3 (w3)	Total (w1*w2*w3)
Bio-physical	0.5833	Topography	0.4545	Slope	0.5833	0.1546
				Elevation	0.4167	0.1105
		Soil	0.1213	Drainage	0.4545	0.0322
				Depth	0.3334	0.0236
				Texture	0.2121	0.0150
		Climate	0.4242	Rainfall	0.667	0.1650
		Total	1.0000	Temperature	0.333	0.0824
Socio-economic	0.4167	Livelihood	0.6670	Population density	0.500	0.1389
				Available land use	0.500	0.1389
		Distance	0.3330	Distance from road	0.340	0.0473
				Distance from river	0.660	0.0916
Total	1.0000	Total	1.0000	Total		1.0000

Land suitability assessment

After the required factor and class weights were derived (ass seen in Tables 21,22,23), land suitability maps could be produced using GIS overlay method available in ArcGIS program where spatial data of the used factors were processed together as a set of GIS layers (13 layers for rubber, 13 layers for forest and 11 layers for urban respectively). The total suitability score for each defined land unit (i.e. each raster cell on the map) was simply calculated from the linear combination of known suitability score for each factor. These scores were derived by multiplying each class weight with all associated factor rating found in each level of the hierarchy (Drobne & Lisec, 2009). Therefore, the calculation of total suitability score could be written as

$$\mathrm{Si} = \sum_{i=1}^{n} Wi \times Ri$$

Where Si represents the total suitability score (for each land unit), n represents the number of factors involved in the analysis (13 for rubber & forest and 11 for urban). Wi is the multiplication of all associated weights in the hierarchy of ith factor and Ri represents the class rating given for specific class of the ith factor found on the assessed land unit. The total suitability scores (for each land unit) had values ranging between 0 and 4 and they were assembled to create land suitability map for each selected land.

Table 24

Defined score ranges for land suitability classification

Suitability class	Suitability score range
Highly suitable area (S1)	3.00-4.00
Moderately suitable area (S2)	2.00-3.00
Less suitable area (S3)	1.00-2.00
Not suitable area (N)	0.00-1.00

CHAPTER 7

RESULTS AND DISCUSSION –II

Land use suitability

Pressure on land has continuously increased because of population growth. To serve increasing demands of land for different purposes, it is necessary to struggle for sustainable land use. Hence, in order to get the optimum benefit from the land, proper utilization of its resources is inevitable. Due to this fact, land suitability study for this specific area is necessary. In Thailand, as in many developing countries, current land use practices is not based on suitability analysis; therefore, there is an urgent need to use land in the most rational and possible ways. In the case of U-tapao river basin, the most important and urgent need is to identify the suitable land uses for sustainable development. In this study multi-criteria decision making (MCDM) integrated with GIS was applied to delineate the suitable areas for agriculture, forest and urban for environment based land use planning purpose.

Land use suitability of agriculture

Suitability analysis of rubber

Compared with other agriculture activities of basin, rubber is dominating land use of U-tapao river basin and it is also an important agricultural activity of the basin. Most part of the basin is covered by rubber trees. Therefore, rubber is very important part of sustainable development of the basin and suitability analysis of rubber should be analyzed for land use planning of the basin. This study is the first study to analyze the suitability of the rubber in the U-tapao river basin. Therefore, for agricultural land use suitability analysis, only land use suitability of rubber has been analyzed. For suitability analysis, many factors and parameters should be considered but in this study, bio-physical and socio-economic factors were considered and these factors were also divided into sub-factors as well. On the basis of sub-factors, 13 layered maps were generated by using GIS which are explained below.

Bio-physical

*Climate***:** The climate is an important factor for land use suitability analysis of rubber because it affects the growth of rubber. Climatic factor has both positive and negative effects on rubber production. In this analysis, only mean annual temperature and rainfall were considered as climate factor.

Temperature: Temperature is an important factor of suitability analysis of rubber. From the data obtained from land development department, Thailand, the temperatures between 26 ^{0}C to 28 ^{0}C are highly suitable for rubber, the temperatures between 29 ^{0}C to 34 ^{0}C or 23 ^{0}C to 25 ^{0}C are moderately suitable for rubber, temperatures between 20 ^{0}C to 22 ^{0}C are less suitable for rubber and temperature below 20 ^{0}C or above 34 ^{0}C is not suitable for rubber (FAO, 1983). The average temperature of the whole basin is about 28 ^{0}C, so all the land of the basin is highly suitable for the rubber for temperature as climate factor.

Rainfall: Rain is also an important factor of land use suitability analysis of rubber. According to land development department, Thailand, the annual rainfall between 1500 mm to 2500 mm is highly suitable for rubber, 2500 mm to 4500 mm or 1200mm to 1500 mm is moderately suitable for rubber, 4500 mm to 5000 mm or 1100 mm to 1200 mm is less suitable for rubber and above 5000 mm or 1100 mm is not suitable for rubber. Analyzing the suitability of rubber in the U-tapao river basin, it was found that about 669.15 km^2 (29.03%) land is highly suitable for rubber, 1,329.98 km^2 (57.70%) land is moderately suitable for rubber and only 305.87 km^2 (13.27%) land is not suitable for rubber. In the basin, most of the area is highly or moderately suitable for rubber and only 13.27% is not suitable for rubber on the basis of rainfall.

Topography: Topography is an important determinant of land suitability for rubber. Absolute height is considered because it is deemed to prohibit development of rubber production. Land slope is even more important from an ease of rubber tree planting and construction and an erosion hazard point of view. Slope is also important for soil formation and management because of its influence on runoff, soil drainage, and use of machinery.

Slope: Land development department, Thailand has mentioned that the slope angle between 0 to 12 degrees is highly suitable for rubber, the angle between 12 to 20 degree is moderately suitable, the angle between 20 to 35 degrees is less suitable, and above 35 degrees is not suitable for rubber. In the basin, most of the land 2149.64 km^2 (93.26%) is highly suitable for rubber with respect to slope, 132.08 km^2 (5.72%) land is moderately suitable, 6.45 km^2 (0.28%) land is less suitable for rubber and 16.83 km^2 (0.73%) land is not suitable.

Elevation: Even though elevation is an important factor for land use suitability analysis, most of researches haven’t mentioned it as a factor, and land development department, Thailand also has not mentioned it clearly as a factor. For this study, from the experts’ opinion and available literature baseline values of elevation were derived. The altitude between 0-200 m from sea level is highly suitable for rubber, 200-400 m is moderately suitable, 400-600 m is less suitable and more than 600 m is not suitable for rubber (Ranst et al., 1996). So, in the basin, the most of land area about 1985.06 km^2 (86.12%) is highly suitable for rubber with respect to elevation, 99.58 km^2 (4.32%) land is moderately suitable, 165.27 km^2 (7.17%) land is less suitable and 55.09 km^2 (2.39%) land is not suitable for rubber.

Soil: Soil is an important factor for land use suitability analysis. In the context of soil, soil texture provides important information regarding water holding capacity, permeability, irrigation requirement etc. pH is also an important character for soil analysis and it gives an idea of content of acidic or alkaline amount in the soil. Another important factor of soil is soil depth. Soils that are deep well drained, with desirable texture and structure are suitable for rubber production.

pH:. According to land development department, Thailand, pH value between the range 5.1-7.3 is highly suitable for rubber, pH range between 7.4-8.0 or 4.0-5.0 is moderately suitable, pH range between 3.5-3.9 is less suitable and pH range more than 8.0 or less than 3.5 is not suitable for rubber. In the basin, about 315.78 km^2 (13.71%) land is highly suitable for rubber with respect to pH value of soil, 1407.89 km^2 (61.08%) land is moderately suitable, 574.88 km^2 (24.93%) land is less suitable and 6.65 km^2 (0.28%) land is not suitable.

Drainage: The drainage is diagnostic factor of oxygen availability of land quality. According to land development department, Thailand, the drainage is divided into 6 classes. Class 1 is categorized as very poorly drained, class 2 is categorized as poorly drained, class 3 is categorized as somewhat poorly drained, class 4 is categorized as moderately well drained, class 5 is categorized as well drained and class 6 is categorized as excessively drained. Regarding the land use suitability of rubber, the land with drainage class 5 or 6 is highly suitable, class 4 is moderately suitable, class 3 is less suitable and class 1 or 2 is not suitable. In the basin, 1241.47 km^2 (53.87%) land is highly suitable for rubber with respect to land drainage, 634.79 km^2 (27.54%) land is moderately suitable, 235.80 km^2 (10.23%) land is less suitable and 192.69 km^2 (8.36%) land is not suitable.

Depth: According to land development department, Thailand, the soil depth, above 150 cm is highly suitable for rubber, the depth between 50-150 cm is moderately suitable, 30-50 cm is less suitable and less than 30 cm is not suitable. In the basin, 976.63 km^2 (42.37%) land is highly suitable for rubber in terms of soil depth, 821.73 km^2 (35.65%) land is moderately suitable, 174.03 km^2 (7.55%) land is less suitable and 332.61 km^2 (14.43%) land is not suitable.

Nutrient: According land development department, Thailand, the land use suitability of rubber in terms of nutrient is divided into only two categories, highly suitable and moderately suitable. The land is said to be highly suitable if the nutrient level is very high or high level or moderate and moderately suitable if the nutrient level is low level. In the basin, 2299.69 km^2 (99.77%) land is moderately suitable for rubber and 5.31km^2 (0.23%) land is highly suitable.

Soil texture: According to land development department, Thailand, soil textures like *sl, vfs, sil, si, sicl, cl* are required for rubber. The soil textures like *sic, sicl, l, scl, sil, si and cl* are highly suitable for rubber, soil texture like *sl* is moderately suitable, soil texture like *ls* is less suitable and soil textures like *c, g, sc and s* are not suitable (Paibbonsak et al., 2004). In the basin, 1420.57 km^2 (61.63%) land is highly suitable, 753.50 km^2 (32.69%) land is moderately suitable, 14.06 km^2 (0.61%) land is less suitable and 116.86 km^2 (5.07%) land is not suitable for rubber in terms of soil texture.

Socio-economic: In the land use suitability analysis of agriculture, most of the researchers have given high priority on bio-physical aspect compared to socio-economic aspect. In general, socio-economic aspect also plays an important role in land use suitability analysis. In this study, only two factors of socio-economic (distance & livelihood) were considered due to constraint of availability of data. Actually, distance factor measures the market potentiality of rubber, so the distance from main road and rubber factory were considered for marketing aspect of rubber. To measure livelihood, availability of land use and population density of the locality were considered.

Distance

Main road: For socio-economic analysis, the market is an important aspect. For rubber production, the market is also important. After discussion with experts, it was finalized that nearer to main road is more suitable for rubber than farther from main road. In this study, suitability rubber was defined as the distance less than 1 km distance from main road is as highly suitable, distance within the range 1 to 5 km is moderately suitable, distance between 5 to 10 km is less suitable and distance more than 10 km is not suitable. In the study, 555.04 km^2 (24.10%) land area is highly suitable for rubber considering the distance of main road criteria in marketing aspect, 583.31 km^2 (25.30%) land area is moderately suitable, 583.31 km^2 (25.30%) land area is less suitable and 583.31 km^2 (25.30%) land area is not suitable.

Factory: The distance from factory is also important for economic reason. From discussion with experts in this case, distance less than 10 km is considered as highly suitable, between 10 to 15 is considered as moderately suitable, 15 to 20 is considered as less suitable and more than 20 km is considered as not suitable. In the study, 564.53 km^2 (24.49%) land area is highly suitable for rubber on consideration of distance from factory criteria, 1232.94 km^2 (53.48%) land area is less suitable, and 507.53 km^2 (22.03%) land area is not suitable.

Livelihood

Population density: Population of any area is directly linked with livelihood. In suitability analysis of rubber, for socio-economic reason, the population density also plays an important role. From the discussion with experts, in this basin, the population density less than 100 per square kilometer is considered as highly suitable for rubber, population density between 100 to 300 per square kilometer is considered as moderately suitable for rubber, population density between 300 to 500 square kilometer is considered as less suitable and population density more than 500 square kilometer is considered not suitable. In the basin, the land area about 211.72 km^2 (9.18%) is highly suitable considering population density factor, 1461.75 km^2(63.42%) land area is moderately suitable, 603.23 km^2(26.17%) land area is less suitable and 28.89 km^2(1.22%) land area is not suitable.

Land use: In the suitability analysis of rubber, current available land use is also important for planning purpose. In this study, after discussion with experts, we came to the following consensus: current agricultural land use is highly suitable for rubber, grass and shrub land use is moderately suitable, forest land is less suitable and urban and water body are not suitable. In this study, 1695.26 km^2 (73.24%) land area is highly suitable for rubber, considering available land use criteria, 87.18 km^2(3.78%) land area is moderately suitable for rubber, 296.53 km^2 (12.86%) land area is less suitable and 226.03 km^2 (9.80%) land area is not suitable.

Figure 48. Land use suitability of rubber based on temperature criteria

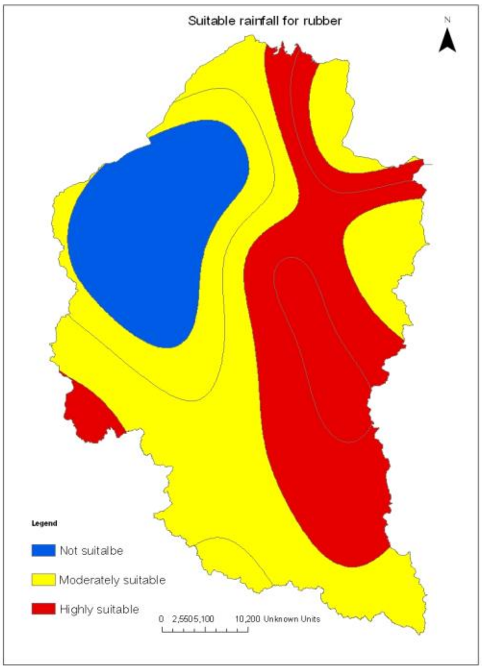


Figure 49. Land use suitability of rubber based on rainfall criteria

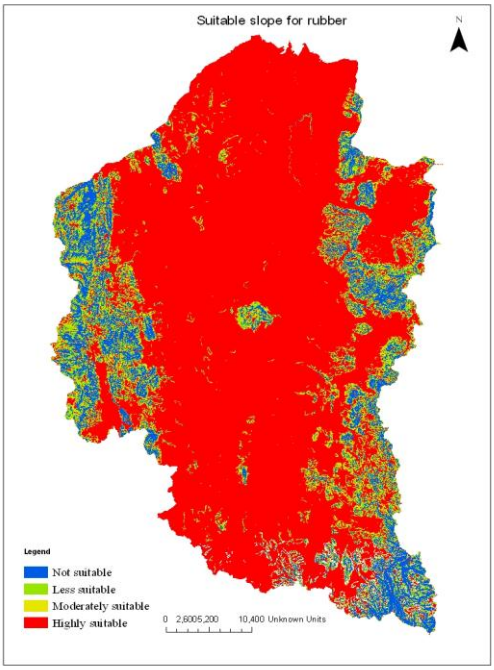


Figure 50. Land use suitability of rubber based on slope criteria

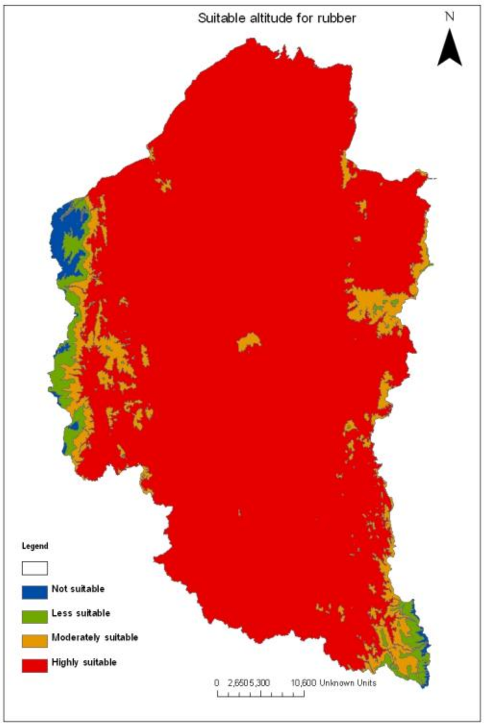


Figure: 51. Land use suitability of rubber based on elevation criteria

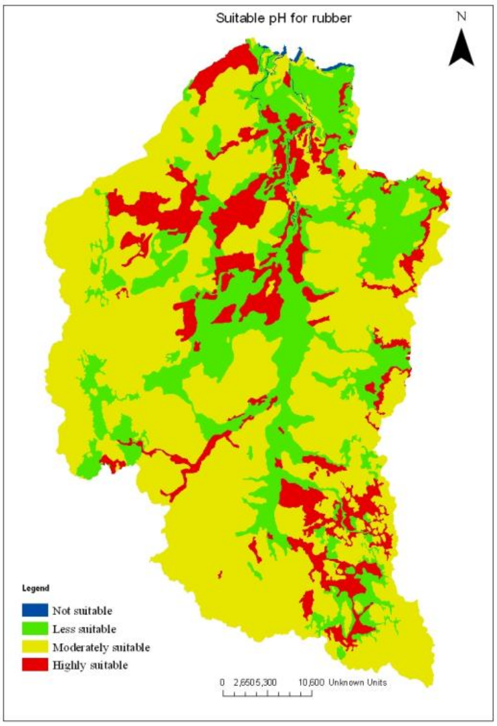


*Figure 52.*Land use suitability of rubber based on soil pH criteria

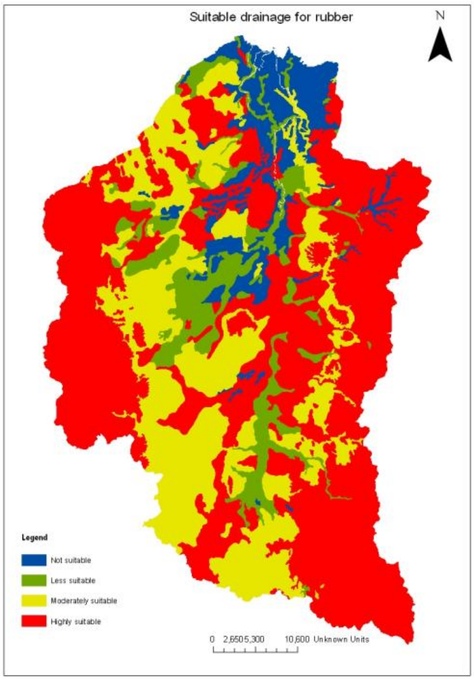


Figure 53. Land use suitability of rubber based on soil drainage criteria

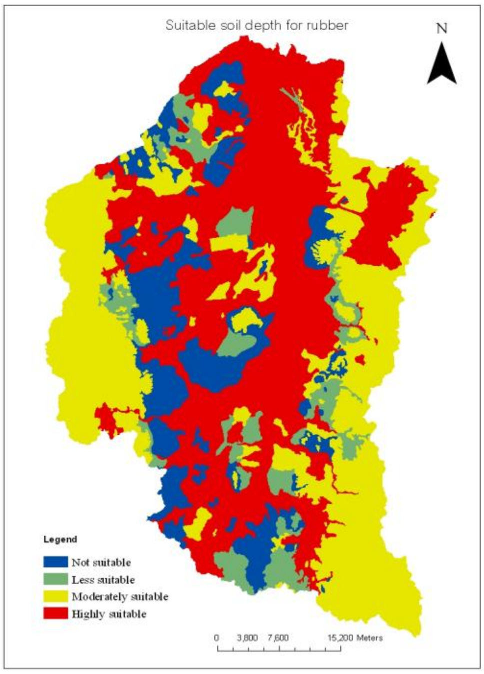


Figure 54. Land use suitability of rubber based on soil depth criteria

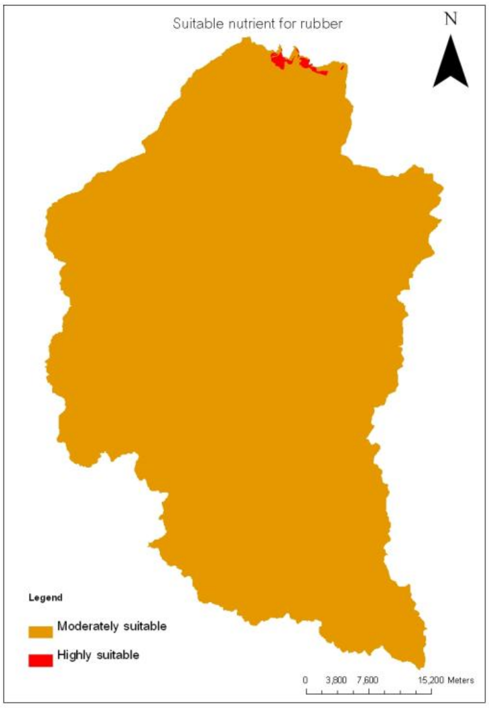


Figure 55. Land use suitability of rubber based on soil nutrient criteria

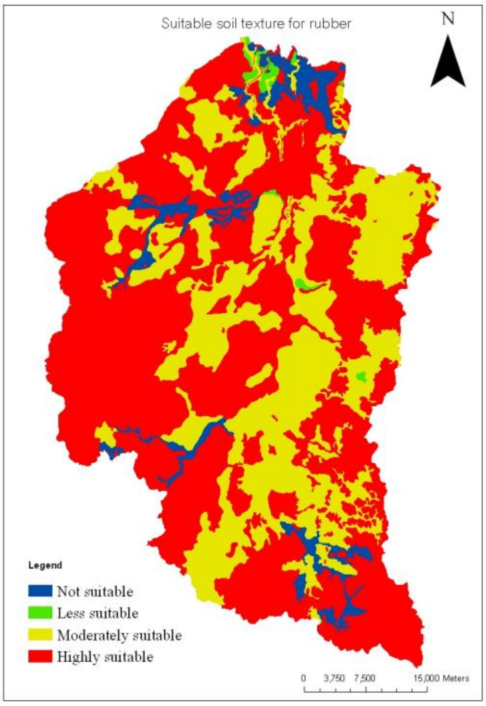


Figure 56. Land use suitability of rubber based on soil texture criteria

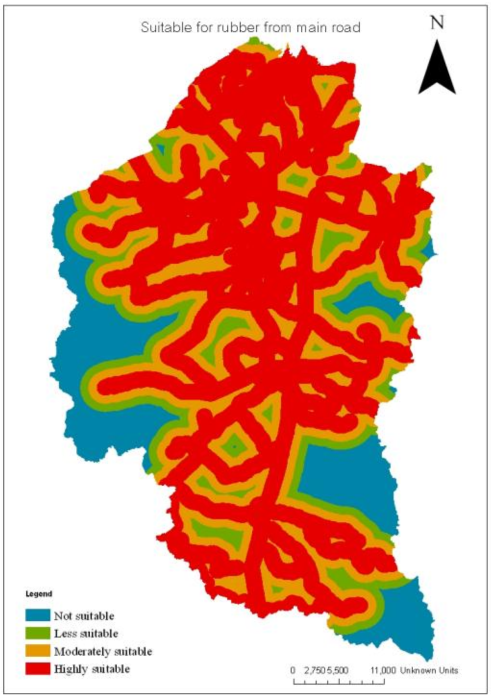


Figure 57. Land use suitability of rubber based on distance from main road criteria

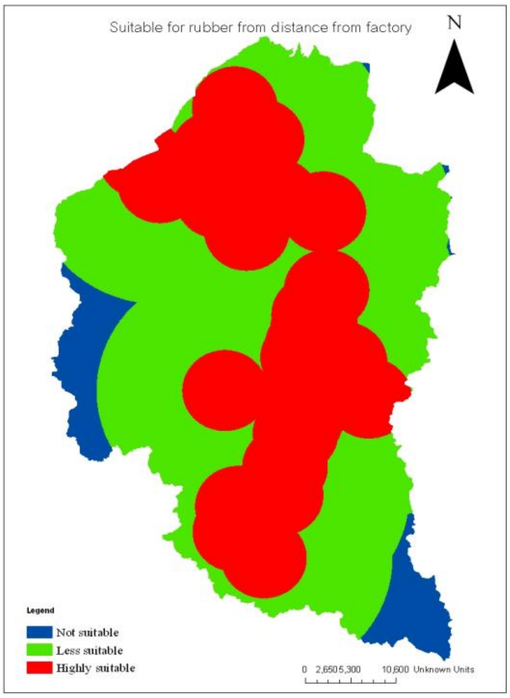


Figure 58. Land use suitability of rubber based on distance from factory criteria

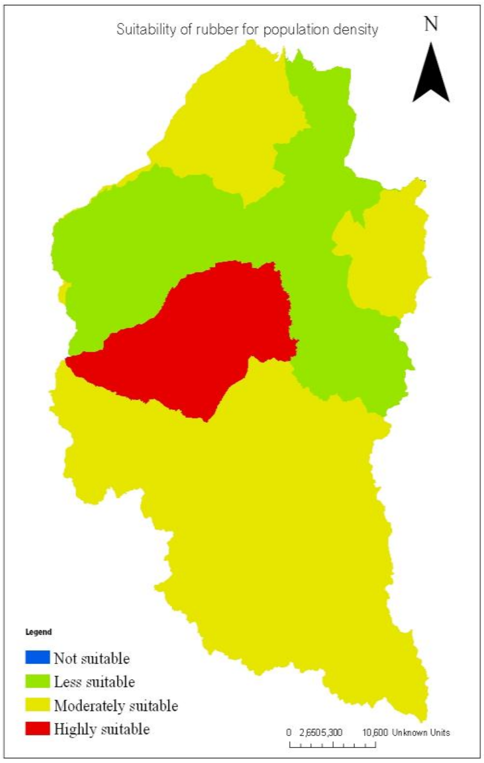


Figure 59. Land use suitability of rubber based on population density criteria

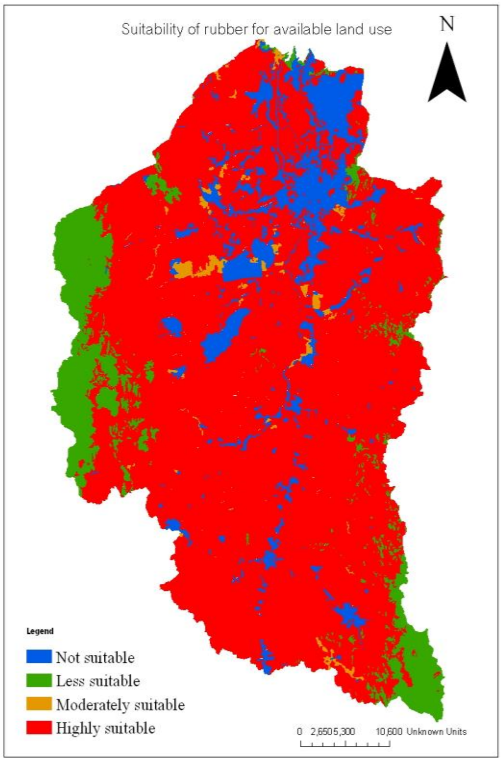


Figure 60. Land use suitability of rubber based on available land use criteria

Land use suitability map of rubber in URB

For suitability analysis of rubber, multi criteria decision making concept was used in GIS environment. For this, two main criteria, bio-physical and socio-economic criteria were established and bio-physical criteria was further divided into 3 sub criteria as climate (temperature & rainfall), topography (slope & elevation) and soil (depth, drainage, pH, texture & nutrient). Socio-economic criteria were also further divided into 2 sub criteria as distance (distance from main road & distance from factory) and livelihood (population density & available land use). Therefore, altogether 13 thematic maps were prepared and the weights of all criteria were developed by pair wise comparison method in AHP. The suitability score was developed based on the linear combination of all rating score and weight. The score between 3.00 to 4.00 was considered highly suitable for rubber, score between 2.00-3.00 was considered as moderately suitable for rubber, score between 1.00-2.00 was considered less suitable and score between 0.00-1.00 was considered as not suitable. For the suitability analysis, the area of water body was fixed or made constraint in analysis process. The suitability map of rubber in U-tapao river basin as follows:

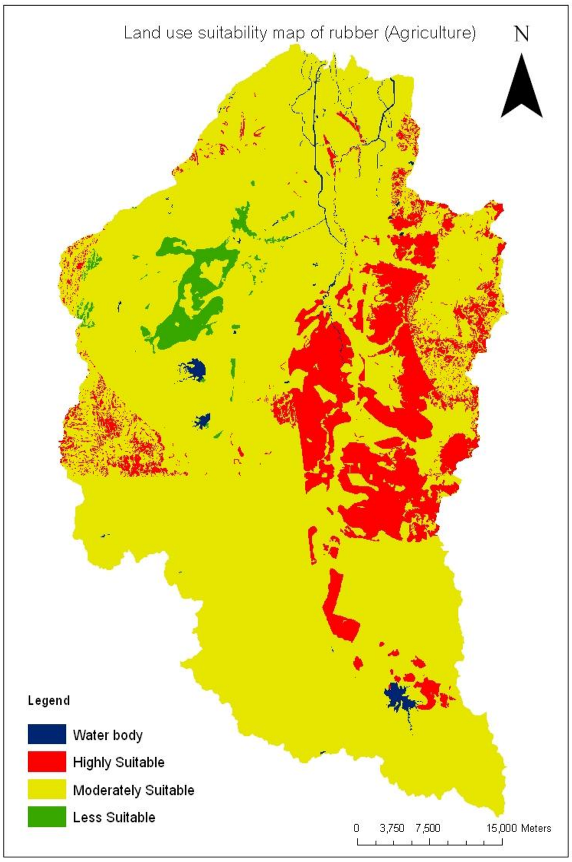


Figure 61. Land use suitability map of rubber in URB

In this study, the highly suitable land for rubber is about 333.34 km^2 (14.46%), moderately suitable land for rubber is about 1901.35 km^2(82.48%), less suitable land for rubber is about 51.07 km^2 (2.22%). There is no non suitable land for rubber in this area. The area of water body is 19.24 km^2 (0.83%).

Land use suitability map of agriculture on URB

For agriculture purpose, it was evaluated only land use suitability of rubber. Since, land uses for other agricultural practices are minimum, it is not reasonable to analyze all of them. To develop final land use suitability map of agriculture, land uses for rice paddy and other agricultural activities were fixed and adjusted with land use suitability map of rubber. The final map of agricultural land use suitability map is shown below (Fig 62). From overall analysis, the most dominating land use of U-tapao river basin is agriculture which covers about 70% of land use of river basin. Out of agricultural land, rubber covers about 65% of land of the basin. In the basin, water body covers about 19.13 km^2 (0.83%), rice paddy field covers about 83.68 km^2(3.63%) and other agricultural activities cover about 37.12 (1.61%). From the land use suitability analysis, highly suitable land use for rubber is 316.46 km^2(13.73%), moderately suitable land use for rubber is 1798.36 km^2(78.02%) and less suitable land use for rubber is 50.24 km^2(2.18%).

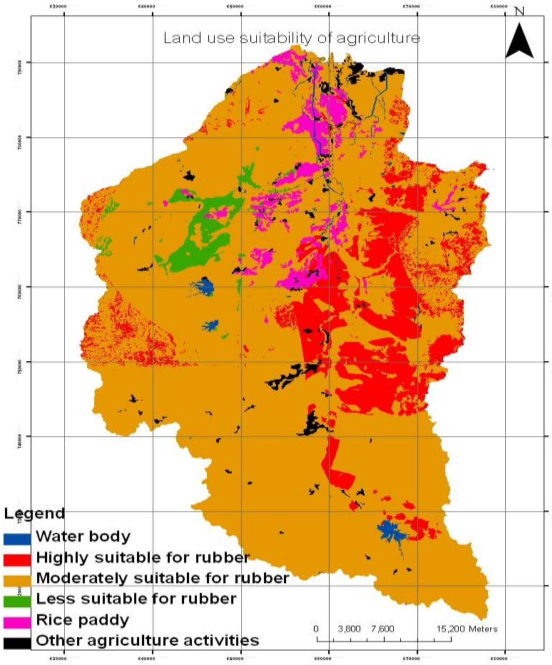


Figure 62. Agricultural land use suitability map of URB, Thailand

Land use suitability analysis of forest

Forested land is an important part of land use planning. Due to urbanization and industrialization process, the virgin forest has been disappearing rapidly. For sustainable development of the any region, environmental aspect should be considered. In the basin, protection of forest is very important. In recent periods, deforestation rate in the U-tapao river basin is stopped, but lack of suitability analysis of forest has affected the effective planning concept for decision makers. This study provides the clear picture of suitability status of forest in the basin level. Similar to agriculture suitability analysis, the study applied multi-criteria technique integrated GIS background to delineate the suitable areas for forest. For suitability analysis, bio-physical and socio-economic factors are considered and these factors were further divided into sub-factors.

Bio-physical

Climate: The climate is an important factor because it affects the growth of vegetation and forest. Climatic factor has both positive and negative effects on forest production. Climatic constraints may cause direct or indirect losses of biomass increments. For this study, annual temperature and rainfall were considered as climatic factor.

Temperature: Temperature is an important factor of suitability analysis of forest. From discussion with forest experts of southern region, the suitability scale is divided into four categories. The temperature between 24 ^{0}C to 28 ^{0}C is considered as highly suitable for forest, temperature between 28 ^{0}C to 30 ^{0}C is considered as moderately suitable for forest, 30 ^{0}C to 32 ^{0}C is considered as less suitable for forest and more than 32 ^{0}C or less than 24 ^{0}C is considered as not suitable.

Therefore, the average temperature of the whole basin which was about 28 ^{0}C, it is highly suitable for forest on temperature criteria.

Rainfall: Rain is also an important factor of land use suitability analysis of forest. From the opinion of forest experts' of southern region, the annual rainfall more than 2000 mm is considered as highly suitable for forest, between 1500-2000 mm is considered for moderately suitable, between 1000-1500 mm is considered as less suitable and less than 1000 mm is considered as not suitable for forest. In the basin, the area about 234.98 km^2 (10.19%) land area is highly suitable for forest on the basis of rainfall, 669.24 km^2 (29.03%) land area is moderately suitable and 1400.77 km^2 (60.77%) land area is less suitable.

Topography: Topography is an important factor for determining of land potential for forest. Land slope is important from an ease of tree plantation and construction and an erosion hazard point of view. Elevation is a critical limiting factor due to the effect of temperature and rainfall. In this study, slope and elevation were considered for topography aspect.

Slope: From forest experts' of southern region, the slope angle between 0 to 12 degree is highly suitable for forest; the angle between 12 to 20 degree is moderately suitable, the angle between 20 to 35 degree is less suitable and above 35 degrees is not suitable for forest. In the basin, the most of area 2149.64 km^2 (93.26%) is highly suitable for forest, 132.08 km^2 (5.72%) area is moderately suitable for forest, 6.45 km^2 (0.28%) area is less suitable for forest and 16.83 km^2 (0.73%) area is not suitable for forest.

Elevation: According to experts' opinion collected for this study and available previous literature, the elevation between 0-400 m from sea level is highly suitable for forest, 400-600 m is moderately suitable, 600-1000 m is less suitable and more than 1000 m is not suitable for forest. From elevation aspect, most of the land area about 2084.64 km^2 (90.44%) is highly suitable for forest and 221.17 km^2 (9.56%) is moderately suitable for forest.

Soil: Similar to agriculture, soil is also an important factor of land use suitability analysis for forest. Soil texture is an important variable for soil and is a key variable in the coupled relationship between climate, topography and vegetation. Therefore it plays an important role in assessment of land suitability analysis for forest. Soil pH needs an important consideration for forestry for several reasons, many tree species prefer either alkaline or acidic conditions and that the soil pH can affect the availability of nutrients in the soil. It varies depending on soil types, slope, rocks, and vegetation type. Soil depth is an important factor affecting soil productivity. Soils that are deep well drained, with desirable texture and structure are suitable for forestry and agriculture production. A soil depth variation from place to place determines the growth of plants and also affects the growing of plant roots.

pH: pH is one of the factors of the soil analysis. For suitability analysis of forest, from forest experts' of southern region, pH value between the range 5-6 is highly suitable for forest, pH range between 4-5 or 6-7 is moderately suitable, pH range between 7-8 or 3-4 is less suitable and pH range more than 8.0 or less than 3 is not suitable for forest. In the study, 1196.93 km^2 (51.92%) land area is highly suitable for forest as pH value of soil, 1102.96 km^2 (47.85%) land area is moderately suitable, and 5.11 km^2 (0.23%) land area is less suitable.

Drainage: From opinion from experts, land use is divided into four categories based on drainage basis. The land is highly suitable for forest for excessively drained or well drained area, moderately suitable for moderately drained area, less suitable for somewhat poorly drained and not suitable for poorly drained or very poorly drained. In the basin, 1241.47 km^2 (53.87%) land area is highly suitable for forest, 634.79 km^2 (27.54%) land area is moderately suitable, 235.80 km^2 (10.23%) land area is less suitable and 192.69 km^2 (8.36%) land area is not suitable for forest.

Depth: From experts' opinion, the soil depth, above 150 cm is highly suitable for forest, the depth between 50-150 cm is moderately suitable, 30-50 cm is less suitable and less than 30 cm is not suitable. In the basin, 976.63 km^2 (42.37%) land area is highly suitable for forest in terms of soil depth, 821.73 km^2 (35.65%) land area is moderately suitable, 174.03 km^2 (7.55%) land area is less suitable and 332.61 km^2 (14.43%) land area is not suitable.

Nutrient: From experts' opinion, land use suitability of forest is divided into two categories, namely highly suitable and moderately suitable. The land is considered highly suitable if the nutrient level is very high or high level and moderately suitable if the nutrient level is moderate or low level. In the basin, 2299.69 km^2 (99.77%) land area is moderately suitable for forest and 5.31km^2 (0.23%) land area is highly suitable.

Soil texture: From experts' opinion the soil textures like *l, scl, and sl* are highly suitable for forest, soil texture like *ls, sil, sc, cl, sicl* are moderately suitable, soil texture like *si, sic, and sc* are less suitable and soil textures like *c, g, ac and s* are not suitable. In the basin, the area 1420.57 km^2 (61.63%) land area is highly suitable, 767.56 km^2 (33.20%) land area is moderately suitable, and 116.86 km^2 (5.07%) land area is not suitable for forest on soil texture basis.

Socio-economic: Generally, socio-economic factors are not included during land suitability of forest. But, this factor very much related and important with respect to forest. Therefore, in this study, distance factor (main road & river) and livelihood factor (available land use and population density) were included as socio-economic factors.

Distance

Main road: For socio-economic analysis, the distance is an important aspect. Following discussion with experts, we reached a consensus as: farther from main road is suitable for forest than nearer from main road. In the study, for suitability forest more than 5 km distance from main road is highly suitable, distance within the range 4 to 5 km is moderately suitable, distance between 3 to 4 km is less suitable and distance less than 3 km is not suitable. In this study, 583.31 km^2 (25.30%) land area is highly suitable for distance of main road criteria, 583.31 km^2 (25.30%) land area is moderately suitable, 583.31 km^2 (25.30%) land area is less suitable and 555.07 km^2 (24.1%) land area is not suitable for forest.

River: The distance from river is also considered in the suitability analysis of forest. According to experts of forest, the nearer the distance from river is the higher the suitability for forest. In this study, the distance less than 500 m is highly suitable for forest, distance between 500 to 1000 m is moderately suitable, distance between 1000 to 2000 m is less suitable and distance more than 2000 m is not suitable for forest. The area about 567.03 km^2 (24.60%) land area is highly suitable for forest, 660.24^2 (28.64%) land area is moderately suitable, 908.98

km^2 (39.43%) land area is less suitable and 168.73 km^2 (7.32%) land area is not suitable for forest.

Livelihood

Population density: In the suitability analysis of forest, population density has been considered on the basis of opinion of experts. According to experts' opinion, population density less than 100 per square kilometer is highly suitable, population density between 100 to 300 per square kilometer is moderately suitable, population density between 300 to 5000 per square kilometer is less suitable and more than 500 per square kilometer is not suitable for forest. In the basin, the area about 22.72 km^2(9.19%) is highly suitable for forest, the area about 1368.59 km^2 (59.37%) is moderately suitable, the area about 93.15 km^2(4.04%) is less suitable and the area about 631.52 km^2 (27.39%) is not suitable.

Land use: In the suitability analysis of forest, current available land use is also important for planning purpose. According to the discussion with experts, current forest land use is highly suitable for forest, grass and shrub land use is moderately suitable, agricultural land is less suitable and urban and water body are not suitable. In the basin, the area 296.53 km^2 (12.86%) is highly suitable for forest, the area 87.18 km^2 (3.78%) is moderately suitable, the area 1695.26 km^2 (73.24%) is less suitable and 226.03 km^2 (9.80%) is not suitable.

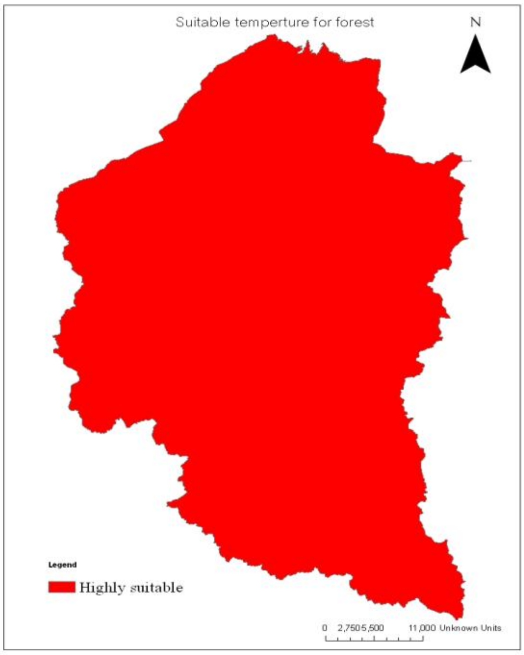


Figure 63. Land use suitability of forest based on temperature criteria

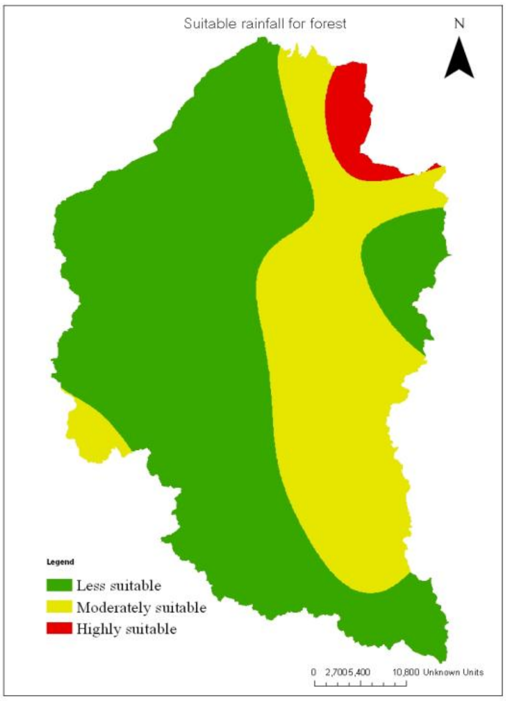


Figure 64. Land use suitability of forest based on rainfall criteria

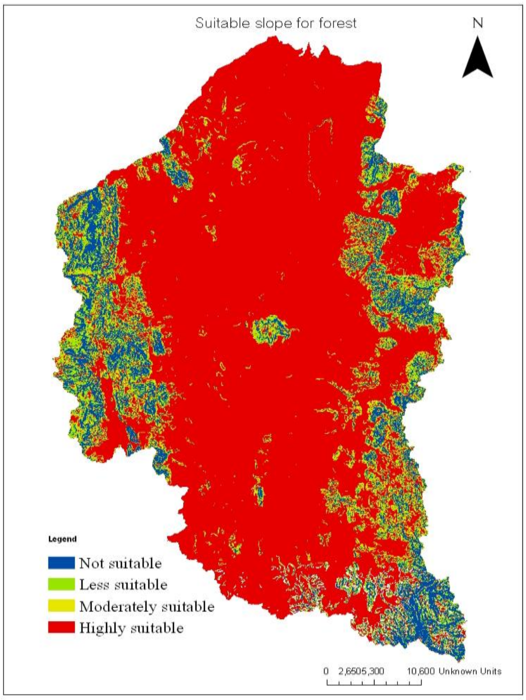


Figure 65. Land use suitability of forest based on slope criteria

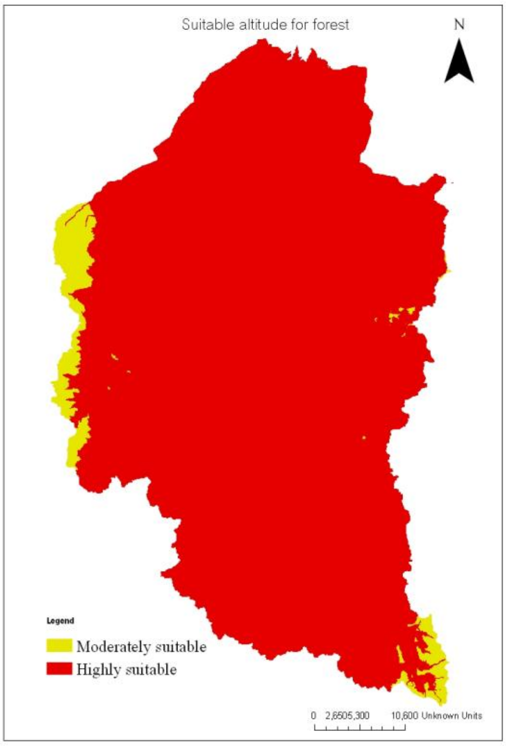


Figure 66. Land use suitability of forest based on elevation criteria

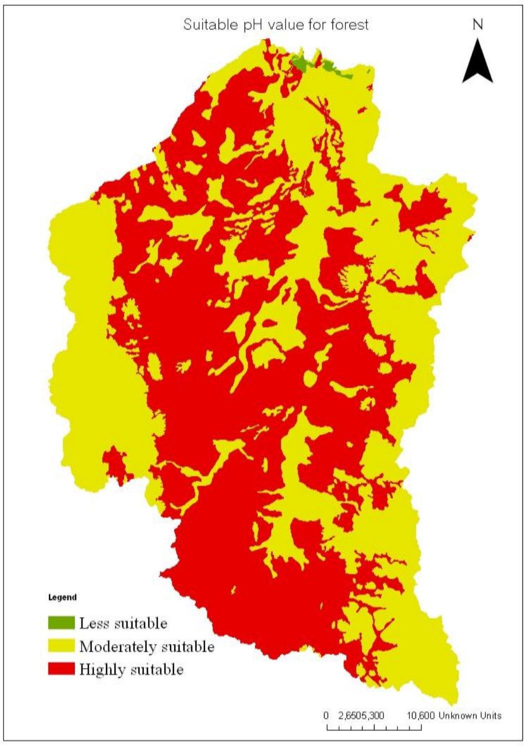


Figure 67. Land use suitability of forest based on soil pH value criteria

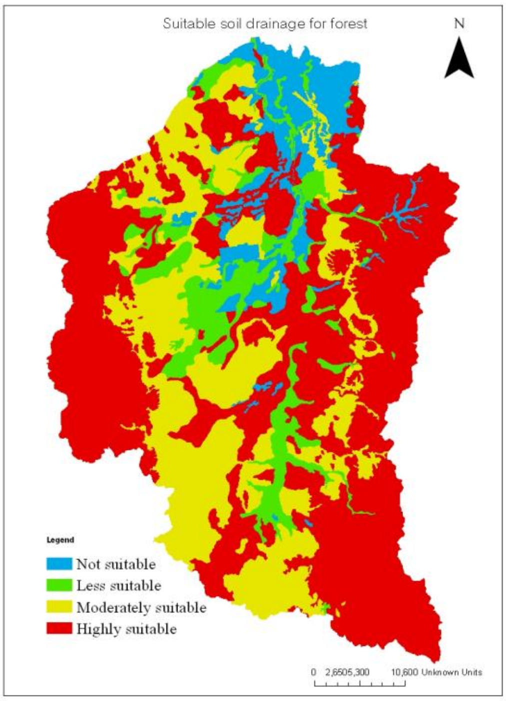


Figure 68. Land use suitability of forest based on soil drainage criteria

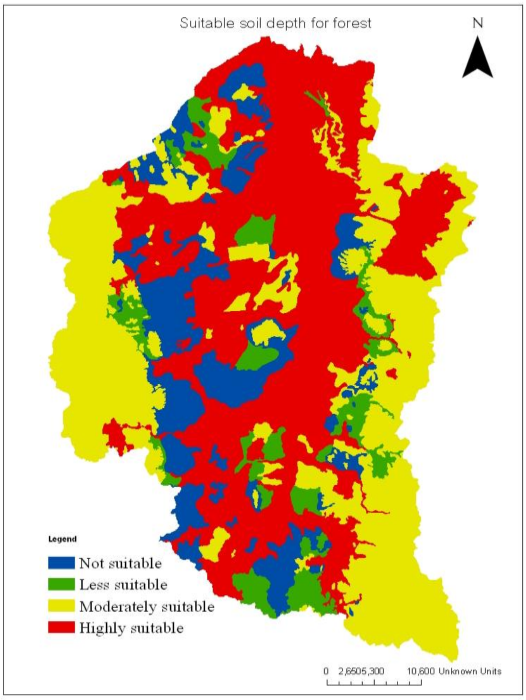


Figure 69. Land use suitability of forest based on soil depth criteria

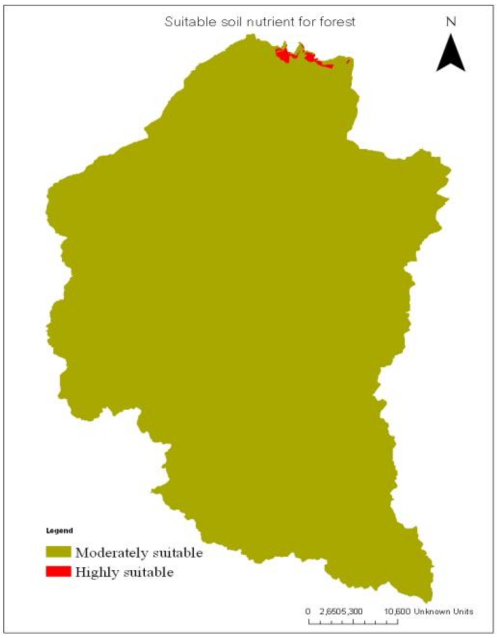


Figure 70. Land use suitability of forest based on soil nutrient criteria

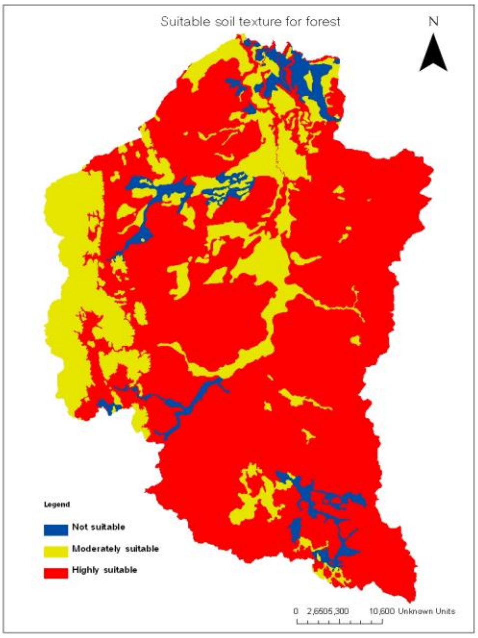


Figure 71. Land use suitability of forest based on soil texture criteria

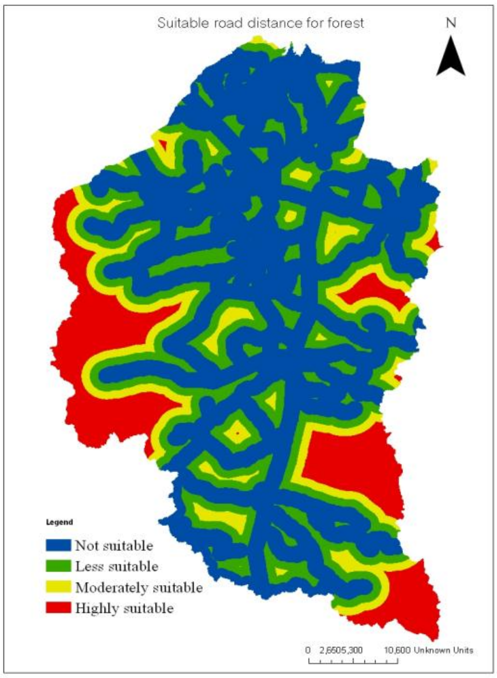


Figure 72. Land use suitability of forest based on distance from main road criteria

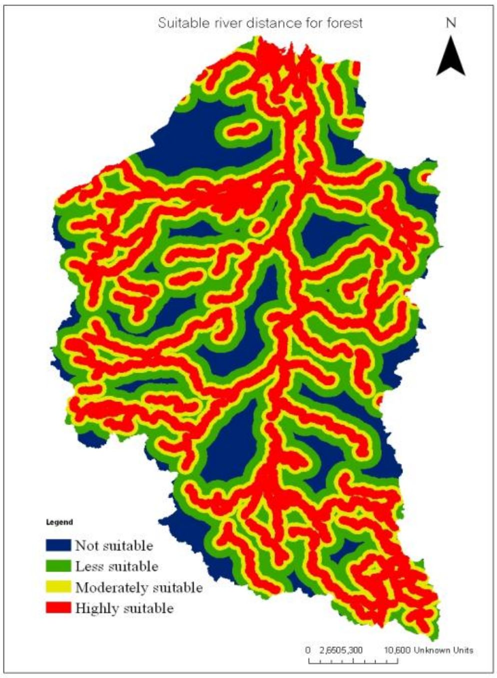


Figure 73. Land use suitability of forest based on distance from river criteria

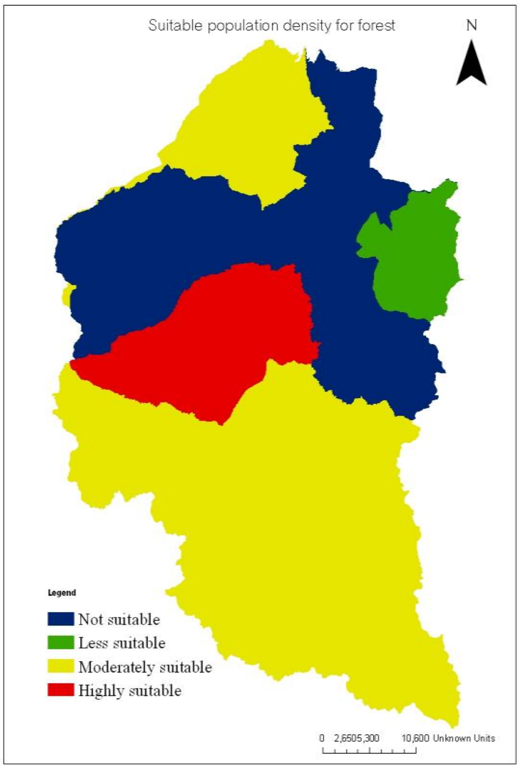


Figure 74. Land use suitability of forest based on population density criteria

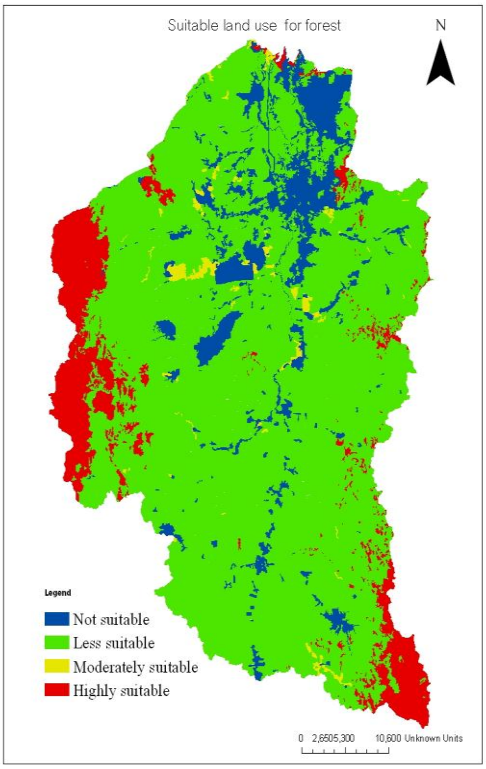


Figure 75. Land use suitability of forest based on available land use criteria

Land use suitability map of forest

For effective forest land use planning, the suitability of forest map was developed by integrating multi criteria decision making (MCDM) process with Geographic Information Systems (GIS). While developing the suitability map, water body was made as constraint factor. Therefore, the final land use suitability map of forest is as shown below (Fig 76). The highly suitable land for forest is about 1375.2 km^2 (59.66%), moderately suitable land for forest is about 910.56 km^2 (39.50%), and less suitable land for forest is very negligible (<0.01 km^2). The area of water body is 19.24 km^2 (0.83%).

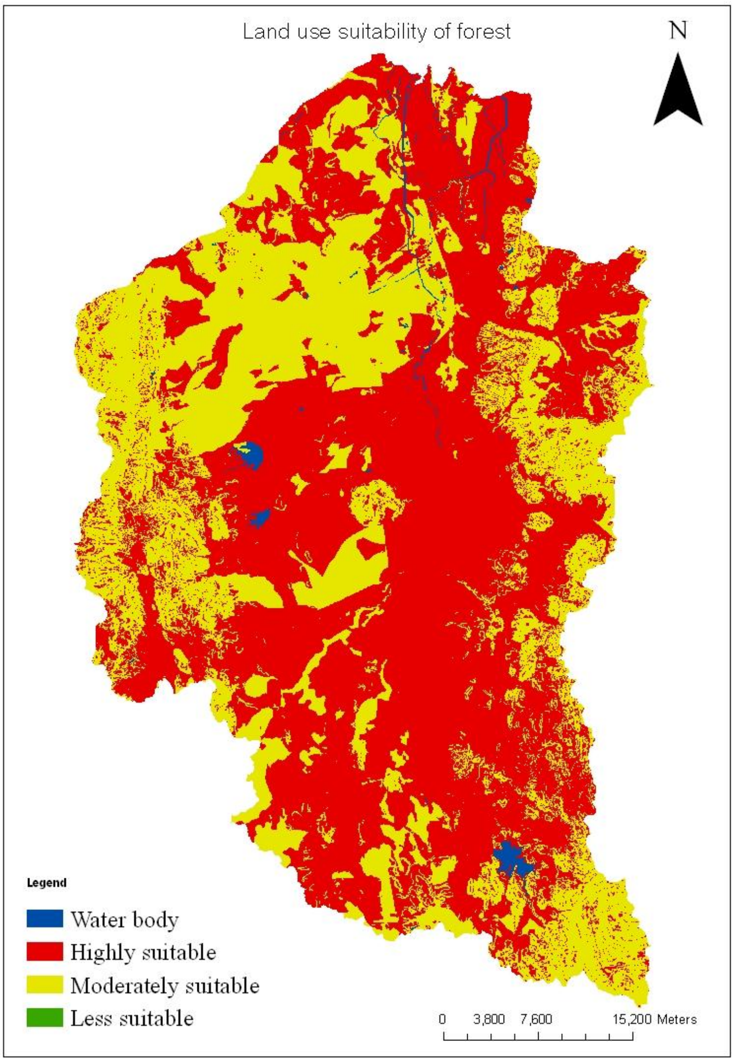


Figure 76. Land use suitability map of forest in URB

Land use suitability analysis of urban

Urban land is also an important part of land use planning. This study tried to provide the clear picture of suitability status of urban area in the basin. Similar to the suitability analysis of agriculture and forest, the study applied multi-criteria technique integrated GIS background to delineate the suitable areas for urban. For suitability analysis, bio-physical and socio-economic factors were considered and these factors were also divided into sub-factors.

Bio-physical

Climate

Temperature: Temperature is an important factor of suitability analysis of urban. From discussion with urban experts of southern region, the suitability scale is divided into four categories. The temperature between 20 ^{0}C to 25 ^{0}C is considered as highly suitable for urban, temperature between 15 ^{0}C to 20 ^{0}C or 25 ^{0}C to 30 ^{0}C is considered as moderately suitable for urban region, 10 ^{0}C to 15 ^{0}C or 10 ^{0}C to 15 ^{0}C is considered as less suitable for urban region and more than 35 ^{0}C or less than 10 ^{0}C is considered as not suitable. Therefore, the average temperature of the whole basin is about 28 ^{0}C, so the land of basin is moderately suitable for urban region.

Rainfall: Rainfall is also an important factor of land use suitability analysis of urban. Generally too much or too less rainfall is not suitable for settlement of human beings. According to the opinion of urban experts' of southern region, the annual rainfall between 500-1000 mm is considered as highly suitable for urban, between 1000-1500 mm is considered for moderately suitable, between 1500-2000 mm is considered as less suitable and less than 500 mm or more than 2000 is considered as not suitable for urban. In the basin, the area about 305.78 km^2 (13.26%) land is highly suitable on the basis of rainfall, 1094.98 km^2 (47.51%) land is moderately suitable, 669.24 km^2 (29.03%) land is less suitable and 234.98 km^2 (10.19%) is not suitable for urban.

Topography

Slope: Slope is an important factor of suitability analysis as topography factor for urban. According to urban experts' of southern region, the slope angle between 0 to 12 degrees is highly suitable for urban; the angle between 12 to 20 degrees is moderately suitable, the angle between 20 to 35 degree is less suitable and above 35 degree is not suitable for urban. In the basin, the most of land area 2149.64 km^2 (93.26%) is highly suitable for urban, 132.08 km^2 (5.72%) area is moderately suitable, and 6.45 km^2 (0.28%) area is less suitable for urban and 16.83 km^2 (0.73%) area is not suitable for urban on slope aspect.

Elevation: According to the experts' opinion and available literature, the elevation between 0-200 m from sea level is highly suitable for urban, 200-400 m is moderately suitable, 400-600 m is less suitable and more than 600 m is not suitable for urban. From elevation aspect, most of the land area about 1985.06 km^2 (86.12%) is highly suitable for urban, 99.58 km^2 (4.32%) is moderately suitable, 165.27 km^2 (7.17%) is less suitable and 55.09 km^2 (2.39%) is not suitable for urban.

Soil

Drainage: According to opinion from experts, suitability is divided into four categories on drainage basis. Excessively drained or well drained area is highly suitable for urban, moderately drained area is moderately suitable, somewhat poorly drained area is less suitable and poorly drained or very poorly drained area is not suitable for urban. In the basin, 1241.47 km^2 (53.87%) land area is highly suitable for urban, 634.79 km^2 (27.54%) land area is moderately suitable, 235.80 km^2 (10.23%) land area is less suitable and 192.69 km^2 (8.36%) land area is not suitable.

Depth: From urban experts' opinion, soil depth more than 150 cm is highly suitable for urban, depth between 100-150 cm is moderately suitable, depth between 50-100 cm is less suitable and depth less than 50 cm is not suitable. In the basin, 898.21 km^2 (38.97%) land is highly suitable for urban in terms of soil depth, 89.50 km^2 (3.88%) land area is moderately suitable , 379.88 km^2(16.48%) land area is less suitable and 937.39 km^2 (40.66%) land area is not suitable for urban.

Texture: From expert opinions and literature survey, soil having sandy character is highly suitable for urban, loamy character is moderately suitable, clayey character is less suitable and rocky and stone character is not suitable for urban (Reghunath, 2006). In the basin, the land area 645.46 km^2 (28.00%) is highly suitable, the land area 709.55 km^2 (30.78%) is moderately suitable, the land area 338.52 (14.68%) is less suitable and the land area 611.45 km^2 (26.53%) is not suitable for urban based on soil texture.

Socio-economic

Distance

Main road: Based on discussion with experts, the nearer to main road is more suitable for urban and vice versa. In this study, for suitability for urban, less than 1 km distance from main road is highly suitable, distance within the range 1 to 5 km is moderately suitable, distance between 5 to 10 km is less suitable and distance more than 10 km is not suitable. In this study, 555.04 km^2 (24.10%) land area is highly suitable based on the distance from main road criteria, 583.31 km^2 (25.30%) land area is moderately suitable, 583.31 km^2 (25.30%) land area is less suitable and 583.31 km^2(25.30%) land area is not suitable.

River: The distance from river is also considered in the suitability analysis of urban. From experts of urban, farther distance from river is highly suitable for urban compared with nearer distance from river. In this study, the distance more than 2000 m is highly suitable for urban, distance between 1000 to 2000 m is moderately suitable, distance between 500 to 1000 m is less suitable and distance less than 500 m is not suitable for urban. The land area about 168.73 km^2 (7.32%) is highly suitable for urban, the land area about 908.98 km^2 (39.43%) is moderately suitable, the land area about 660.24 km^2 (28.64%) is less suitable and the land area about 567.03 km^2 (24.60%) is not suitable for urban.

Livelihood

Population density: Population of any area is directly linked with livelihood. In suitability analysis of urban, the population density also plays an important role with respect to socio-economic reason. From the discussion with experts, in this basin, the population density more than 500 per square kilometer is considered as highly suitable for urban, population density between 300 to 500 per square kilometer is considered as moderately suitable for urban, population density between 100 to 300 square kilometer is considered as less suitable and population density less than 100 square kilometer is considered not suitable. In the basin, the area about 28.28 km^2 (1.23%) is highly suitable, 603.23 km^2(26.17%) is moderately suitable, 1461.75 km^2(63.42%) is less suitable and 211.72 km^2(9.18%) is not suitable for urban development.

Land use: In the suitability analysis of urban, current available land use is also important for the planning purpose. According to the discussion with experts, current urban land use is highly suitable for urban, grass and shrub land use is moderately suitable, agricultural land is less suitable and forest and water body are not suitable. In the basin, the land area 206.89 km^2 (7.97%) is highly suitable for urban, the land area 87.18 km^2 (3.78%) is moderately suitable, the land area 1695.26 km^2 (73.24%) is less suitable and the land area 315.67 km^2 (13.69%) is not suitable for urban.

Figure 77. Land use suitability of urban based on temperature criteria

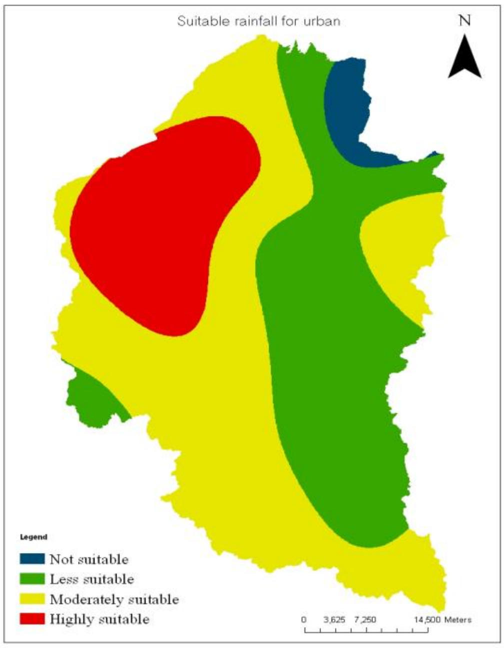


Figure 78. Land use suitability of urban based on rainfall criteria

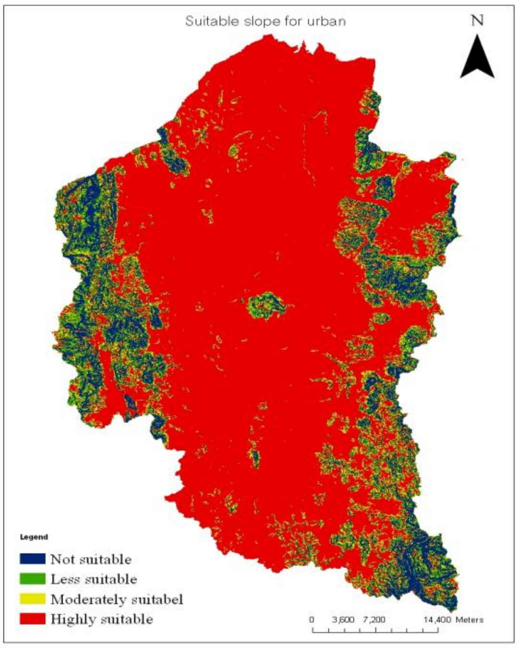


Figure 79. Land use suitability of urban based on slope criteria

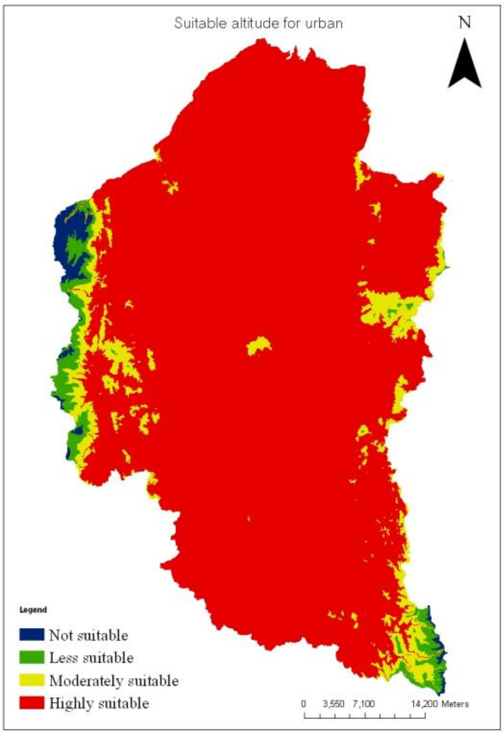


Figure 80. Land use suitability of urban based on elevation criteria

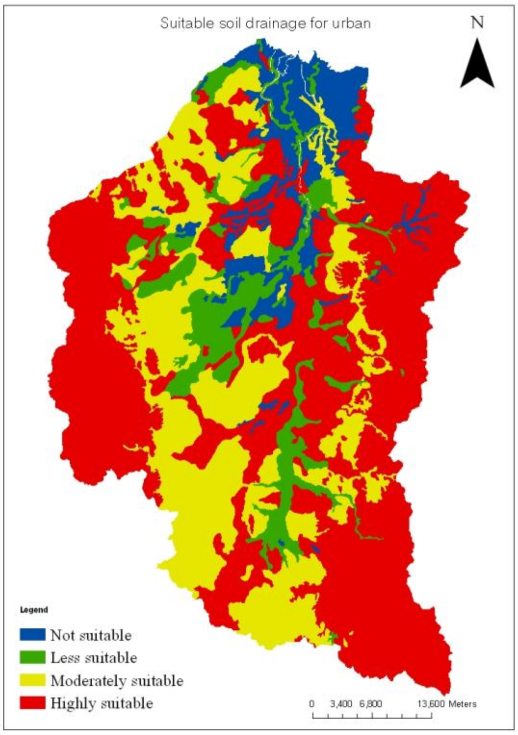


Figure 81. Land use suitability of urban based on soil drainage criteria

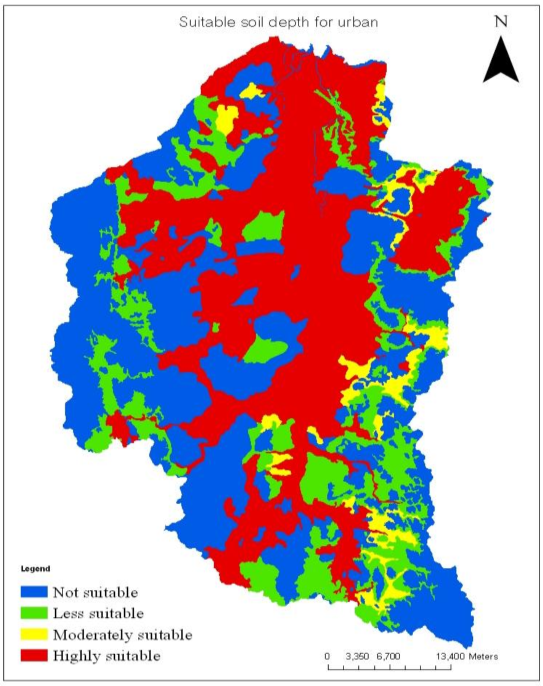


Figure 82. Land use suitability of urban based on soil depth criteria

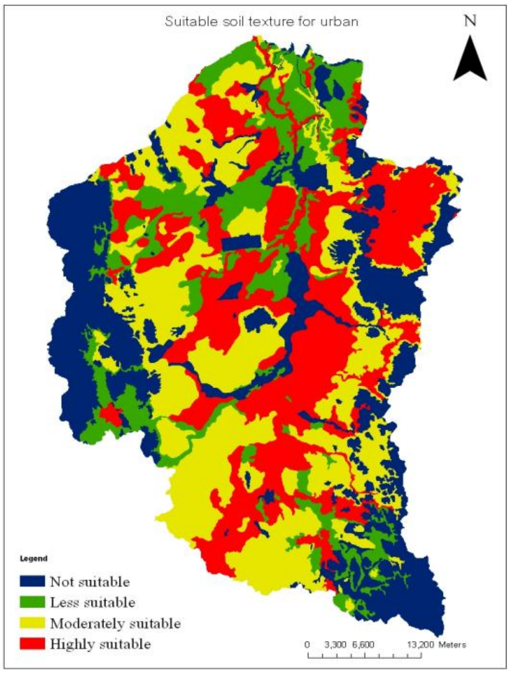


Figure 83. Land use suitability of urban based on soil texture criteria

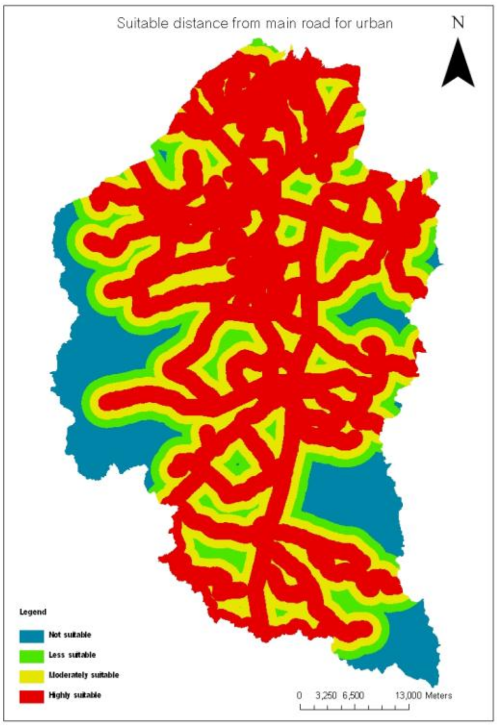


Figure 84. Land use suitability of urban based on distance from main road criteria

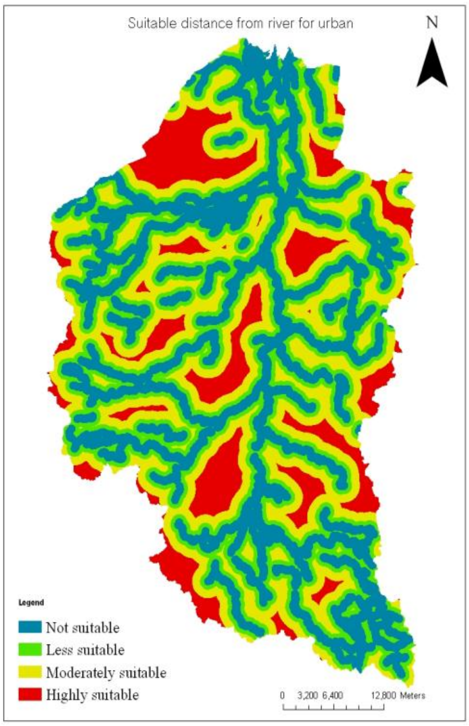


Figure 85. Land use suitability of urban based on distance from river criteria

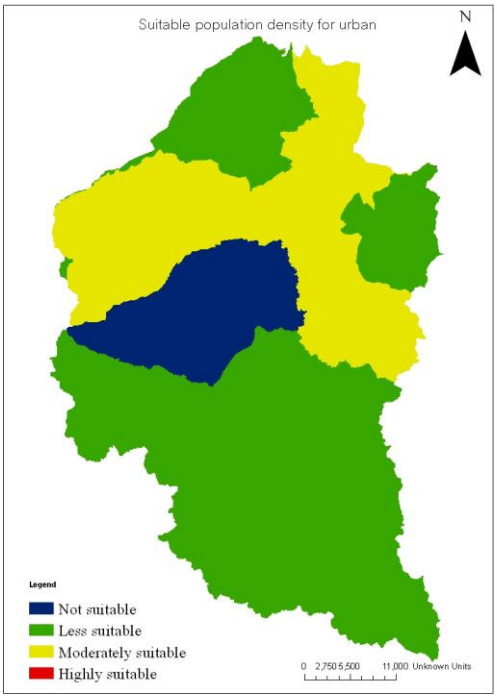


Figure 86. Land use suitability of urban based on population density criteria

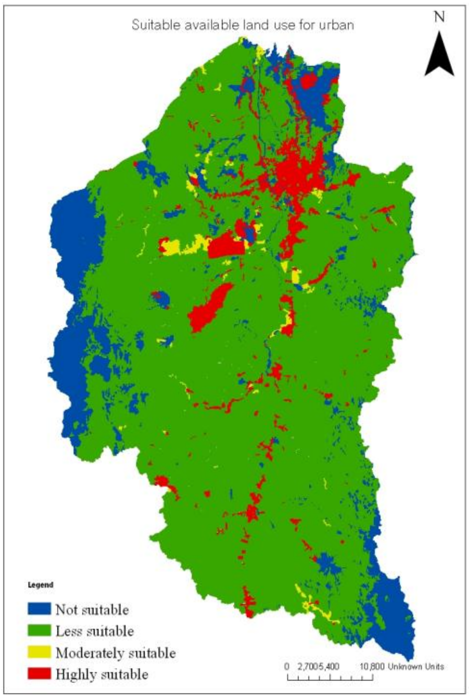


Figure 87. Land use suitability of urban based on available land use criteria

Land use suitability map of urban land use of URB

Similar to agriculture and forest land use suitability maps, the urban land use suitability map is also developed by integrating multi criteria decision making (MCDM) with Geographic information Systems (GIS). During this process, water body of the basin was fixed as constraint. The land use suitability map of urban is presented as below (Figure 88). In the map, the highly suitable land for urban is about 309.79 km^2 (13.44%), moderately suitable land for urban is about 1924.93 km^2(83.51%), less suitable land for urban is 51.04 (2.21%). There is no non suitable land for urban in this area. The area of water body is 19.24 km^2 (0.83%).

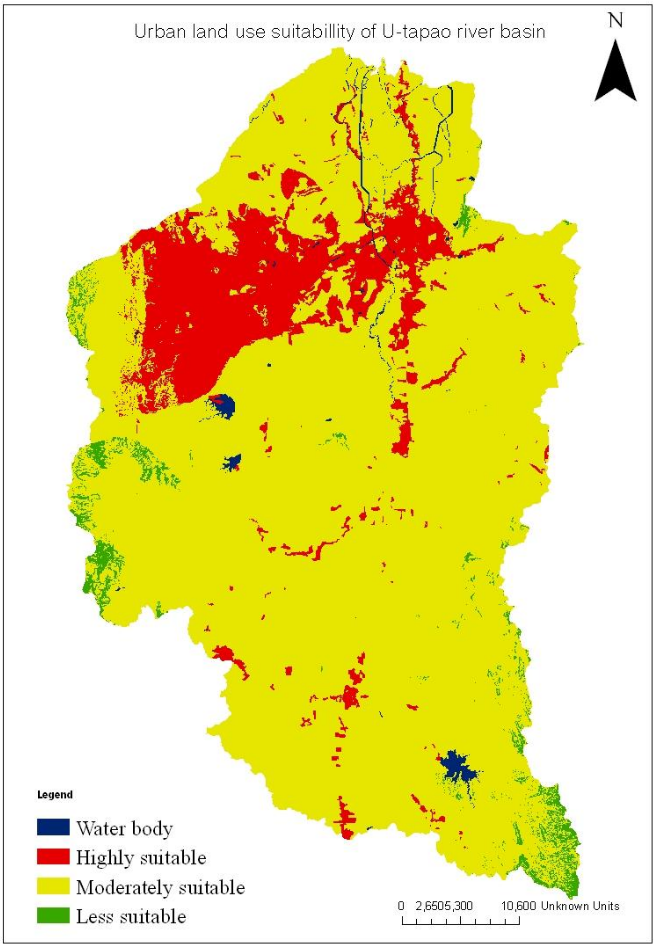


Figure 88. Land use suitability map of urban on URB

Comparison of land use suitability of agriculture, forest and urban in URB

In this study, land use suitability analysis of agriculture, forest, and urban has been done in URB. For suitability analysis, different factors have their own importance and constraint which influences suitability assessment. Overall, land use suitability analysis has been done based on two main criteria: bio-physical and socio-economic criteria. A bio-physical criterion is further subdivided into three sub-criteria (climate, topography and soil) and a socio-economic criterion is also further subdivided into two sub-criteria (distance and livelihood) and these criteria and sub-criteria are also classified into different factors. Therefore, comparing land use suitability analysis of agriculture, forest, and urban, different land uses have different results. Considering the case of climate factor, for temperature criteria, the whole basin totally was highly suitable for agriculture and forest land use purposes whereas moderately suitable for urban land use perspective. With respect to rainfall, it was highly suitable land for agriculture is 29.03%, forest land is 10.19% and urban land is 13.26%. Therefore, from rainfall point of view, agriculture is more suitable than forest and urban cases. Regarding slope of the land, highly suitable land for agriculture, forest and urban land uses is 93.26%, therefore, the basin is highly suitable for all three types of land uses with respect to slope. In the case of elevation, highly suitable area for agriculture is 86.92%, for forest is 90.44% and for urban is 86.92%. So, from elevation aspect, the basin is highly suitable for forest. In the case of soil pH value, the highly suitable area for agriculture is 13.71% and for forest is 51.92%. From pH value aspect, basin is highly suitable for forest. Regarding soil drainage, the basin is highly suitable for all types of land uses. Regarding the soil depth, the basin is highly suitable for both agriculture and forest. Similarly, from the aspect of soil nutrient, the basin is highly suitable for both agriculture and forest land uses. Similarly, from the aspect of soil texture, the basin is highly suitable for both agriculture and forest land uses. From socio-economic aspect, the basin is slightly more suitable forest considering both the distance form main road and the distance from river network. From the viewpoint of population density, forest land is slightly more suitable than agricultural land use. From available land use, agriculture is highly suitable than forest and urban land.

Overall, about 13.73% land area is highly suitable for agriculture, 59.66% land area is highly suitable for forest and 13.44% land area is highly suitable for urban. Similarly, 78.02% land area is moderately suitable for agriculture, 39.50% land area is moderately suitable for forest and 83.51% land area is moderately suitable for urban. Similarly, 2.18% land area is less suitable for agriculture, 0.001% land area is less suitable for forest and 2.21% land area is less suitable for urban. Analyzing all aspects of suitability, the basin is highly or moderately suitable for all agriculture, forest and urban land uses; it is comparatively more suitable for forest land use. But, in practice agriculture is the dominating land use of the basin. From environmental point of view, the basin should be protected for forest land use and side by side, agricultural practice can be done with minimum impact on environment.

Table 25

Comparison of land use suitability of agriculture, forest and urban in URB

Factor	Highly suitable (S1)			Moderately suitable (S2)			Less suitable (S3)			Not suitable (N)		
	AGR	FOR	URB	AGR	FOR	URB	AGR	FOR	URB	AGR	FOR	URB
Temperature	100.00	100.0	---	----	----	100.00	----	----	----	----	----	----
Rainfall	29.03	10.19	13.26	57.70	29.03	47.51	-----	60.77	29.03	13.27	----	10.19
Slope	93.26	93.26	93.26	5.72	5.72	5.72	0.28	0.28	0.28	0.73	0.73	0.73
Elevation	86.12	90.44	86.12	4.32	9.56	4.32	7.17	---	7.17	2.39	----	2.39
pH	13.71	51.92	---	61.08	47.85	----	24.93	5.11	----	0.28	----	----
Drainage	53.87	53.87	53.87	27.54	27.54	27.54	10.23	10.23	10.23	8.36	8.36	8.36
Depth	42.37	42.37	38.97	35.65	35.65	3.88	7.55	7.55	16.48	14.43	14.43	40.66
Nutrient	0.23	0.23	----	99.77	99.77	----	-----	-----	-----	-----	-----	-----
Texture	61.63	61.63	28.0	32.69	33.20	30.78	0.16	----	14.68	5.07	5.07	26.53
Road	24.10	25.30	24.10	25.30	25.30	25.30	25.30	25.30	25.30	25.30	24.1	25.3
Factory	24.49	----	----	----	-----	----	53.48	----	-----	22.03	----	-----
River	-----	24.60	7.32	-----	28.64	39.43	-----	28.64	28.64	----	7.32	24.60
P. density	9.18	9.19	1.23	63.42	59.37	26.17	26.17	4.04	63.42	1.22	27.39	9.18
Land use	73.24	12.86	7.97	3.78	3.78	3.78	12.86	73.24	73.24	9.80	9.80	13.69

Sustainable land-use planning

Sustainable development is the balance between economical, social and environmental aspect. However, in practice, it is very difficult to adjust these factors. Land use planning is influenced by socio-economic development of society and it very complex to adjust environmental issues. Since sustainable means causing little or no damage to the environment and able to continue for a long time, sustainable land use planning should consider environment, social and economic issues for long period of time. The Canadian Institute of Planners (2000) defines sustainable land use planning as: the scientific, aesthetic, and orderly disposition of land, resources, facilities and services with a view to securing the physical, economic and social efficiency, health and well-being of urban and rural communities. Generally, land use planning involves zoning of appropriate types and forms of land uses, as well as infrastructure and open space planning directed at the efficient utilization of land in order to provide benefits to the broader population, the economy and the environment. Sustainable land use planning requires recognition of the limitations of the biosphere and the need for a balance of social, cultural and economic uses within these natural limitations (Chalifour, 2007). According to the guidelines published by FAO, (1993) sustainable land use planning is the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the best land use options. The purpose of land use planning is "to select and put into practice those land uses that will meet the needs of the people best while safeguarding resources for the future" (FAO, 1993). Land-use planning may be defined as a systematic process for the arrangement and allocation of land resources among period of time and space in accordance with the principles of sustainable land-use (Tu, 2010).

Sustainable land use planning is very much related with allocation of suitable land for the requirement of the society. Generally, land suitability is the fitness of a given type of land for a defined use and assessment of land suitability is made by comparison between land use and land quality, coupled with analysis in environmental, economic and social terms (FAO, 1984). Suitability is a measure of how well the characteristics of a land match the requirements of sustainable development. The preparation of sustainable development plan requires consideration of all components of the economic, social and environment as well as properly analysis of land suitability and allocation of land uses with sustainable principle. Mendoza (1996) mentioned that for land use planning by using GIS and MCDM is based on two critical issues: land use suitability and land use allocation. Land use suitability is generic term associating a combination of factors and their impacts with respect to potential land uses. Land allocation, on the other hand, involves the process of designing on optimal mix of land uses base on their estimated suitability and perceived for sustainable management objective. Savoray et al. (2005) used GIS and MCDM concept for sustainable land use planning in Ma'ale Adumim, Israel. First of all, they developed the land use suitability maps of forest, industry, residence and natural resources and allocated theses maps by subjective approach in suitable places for final land use planning. They focused by incorporating ecological/environmental considerations with socio-economic and cultural information for sustainable development. Wang et al. (2006) proposed land use planning by allocating land by using GIS-optimization modeling concept in Lake Erhai Basin, China. By applying multiple objectives (economic, forest, soil loss, water quality) and adjusting constraints (land availability, agricultural, production, tourism, soil loss etc.), they proposed land use planning for sustainable development of Lake Basin. Zarkesh et al. (2010) proposed land use planning on considering various environmental and socioeconomic factors in Teleghan basin, Iran. By studying land use suitability of rangeland, urban development and irrigated agriculture and allocating land use by using Multi-objective land allocation (MOLA) module in IDRRISI Kilimanjaro software, they proposed land use planning giving higher priority rangeland and agricultural uses and less priority of urban development for sustainable development of basin. Sui et al. (2006) proposed land use planning for Qinling mountains, China for sustainable development on this region. The proposed planning was based on consideration for sustainable development of ecosystems within the land form and allowed a steady improvement in biological productivity of mountain land. Tudes & Yigiter (2010) proposed land use planning on the base of land use suitability of urban, industrial, waste disposal and green land for sustainable development of Adana, Turkey by using the concepts of MCDM, AHP and GIS. They also recommended that economic, legal, political and technological factors should be adjusted in sustainable land use planning.

In the case of U-tapao river basin, the proposed planning map of the basin has been tried to adjust sustainable principle. Since, the environmental aspect is one of the pillars of sustainable development, forest and water body of the basin has tried to protect for future or fixed for land use planning process. The main problem of basin is conversion of agricultural land to urban land. From socio-economic aspect, it is not possible to ignore these two factors. Considering these factors, the suitability land use structures of agriculture and urban were analyzed. In land use planning process, allocation of land is one of the main parts of decision makers. Allocation of land can be done either subjective or objective approach. In this study, allocation of agricultural land and urban land were allocated by priority basis as subjective approach. For priority setting, pair wise comparison method was used adjusting the opinion of land use planning expert. Due the reality of the basin, the expert has given more priority on agriculture rather than urban (Priority ranking: Highly suitable area for agriculture > Highly suitable area for urban > Moderately suitable area for agriculture > Moderately suitable area for urban > Less suitable area for agriculture > Less suitable area for urban).

Since, the forest land (12.86%) and water body (0.83%) were fixed or protected, by using GIS application, the high suitable land for agriculture was allocated in the first and it occupied 13.20% land of the basin. Then after, the high suitable land for urban was allocated and it occupied 9.43% of land of the basin. Then after, the moderate suitable land for agriculture was allocated and it occupied 63.41%

land of the basin. Then after, the moderate suitable land for urban was allocated and it occupied 0.26% land of the basin. By this process, the whole basin was divided into different zones as figure below (Figure 89). Therefore, this study proposed the land use planning map of the basin and believed that it is based on sustainable development principle.

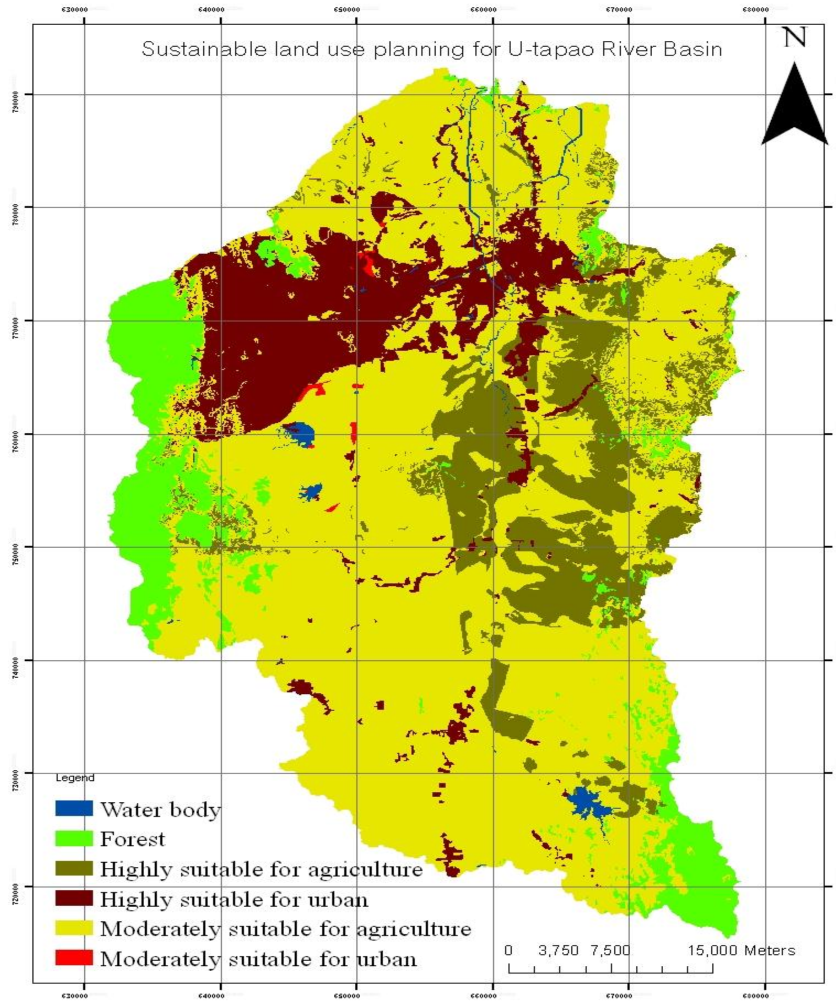


Figure 89. Sustainable land use planning of URB

Division of land use in different zones

Water zone: The total area of water zone is 19.38 km^2 (0.83%) and within water zone sub-land uses like river canal (1.23 km^2), lake (0.05 km^2), reservoir (12.48 km^2), farm pond (0.58 km^2) and irrigation canal (4.94 km^2) were identified by comparing the land use map of the year 2009.

Forest zone: The total area of forest zone is 296.52 km^2 (12.86%) and within forest zone, the area of evergreen forest was 289.27 km^2, swamp forest was 0.72 km^2 and mangrove forest was 6.53 km^2 by comparing the land use map of the year 2009.

Highly suitable area for agriculture zone: The total area of highly suitable land for agriculture zone is 304.21 km^2 (13.20%) and within this zone, rice paddy (17.09 km^2), rubber (254.17 km^2), palm oil (4.13 km^2), orchard (4.54 km^2), grass and shrub (0.093 km^2), wetland (0.01 km^2), mining (0.23 km^2) and urban (23.947 km^2) were identified by comparing the land use map of the year 2009.

Highly suitable area for urban zone: The total area of highly suitable land for urban zone is 217.46 km^2 (9.43%) and within this zone, rice paddy (7.12 km^2), rubber (94.80 km^2), palm oil (3.31 km^2), orchard (6.63 km^2), aquaculture (3.37 km^2) grass and shrub (15.39 km^2), wetland (1.64 km^2), mining (1.93 km^2) and urban (81.89 km^2) and airport (1.38 km^2) were identified by comparing the land use map of the year 2009.

Moderately suitable area for agriculture zone: The total area of moderately suitable land for agriculture zone is 1461.57 km^2 (63.41%) and within this zone, rice paddy (53.84 km^2), rubber (1201.34 km^2), palm oil (12.68 km^2), orchard (23.88 km^2), aquaculture (5.07 km^2), farm house (0.83 km^2), grass and shrub (12.23 km^2), wetland (37.697 km^2), mining (12.1 km^2) and urban (90.59 km^2) and airport (11.21 km^2) were identified by comparing the land use map of the year 2009.

Moderately suitable area for urban zone: The total area of moderately suitable land for urban is 5.86 km^2 (0.26%) and within this zone, rubber (3.89 km^2), palm oil (0.02

km^2), grass and shrub (0.09 km^2), mining (1.82 km^2) and urban (0.039 km^2) were identified by comparing the land use map of the year 2009.

Table 26
Land use distribution in different zones (in km^2)

Zone	%	Area of land use distribution in the year 2009 (in km^2)				Total
		WTB	FOR	URB	AGR	
Water (WT)	0.83	19.38	-	-	-	19.38
Forest (FOR)	12.86	-	296.52	-	-	296.52
Highly suitable agriculture (HSA)	13.20	0.33	-	23.947	279.93	304.21
Highly suitable urban (HSU)	9.43	18.96	-	83.27	115.23	217.46
Moderately suitable agriculture (MSA)	63.42	62.127	-	101.8	1297.64	1461.57
Moderately suitable urban (MSU)	0.26	1.91	-	0.04	3.91	5.86
Total	100.00	102.57	296.52	209.06	1696.71	2305.00

Comparing the proposed sustainable land use planning of URB and actual land use map of the year 2009, it is possible to apply land utilization concept in the basin. For example, the highly suitable area for agriculture zone, 0.93 km^2 area of grass and shrub land and 0.23 km^2 area of mining land can be used for agriculture purpose as rubber plantation. Similarly, highly suitable area for urban zone, 15.39 km^2 shrub and grass land can be used for new urban development. For the case of moderately suitable agriculture zone, 12.23 km^2 grass and shrub land can be used for rubber plantation purpose. For the case of moderately suitable urban zone, 0.039 km^2 can be used for urban development. Therefore, in the basin, grass & shrub land and mining land were not used in proper order or these lands existed as waste land in the basin. For managing sustainable development, these lands should be used for rubber plantation and urban development purpose which might improve living condition of people as well as protect environment. This is the proposed concept for sustainable development of river basin by managing land use.

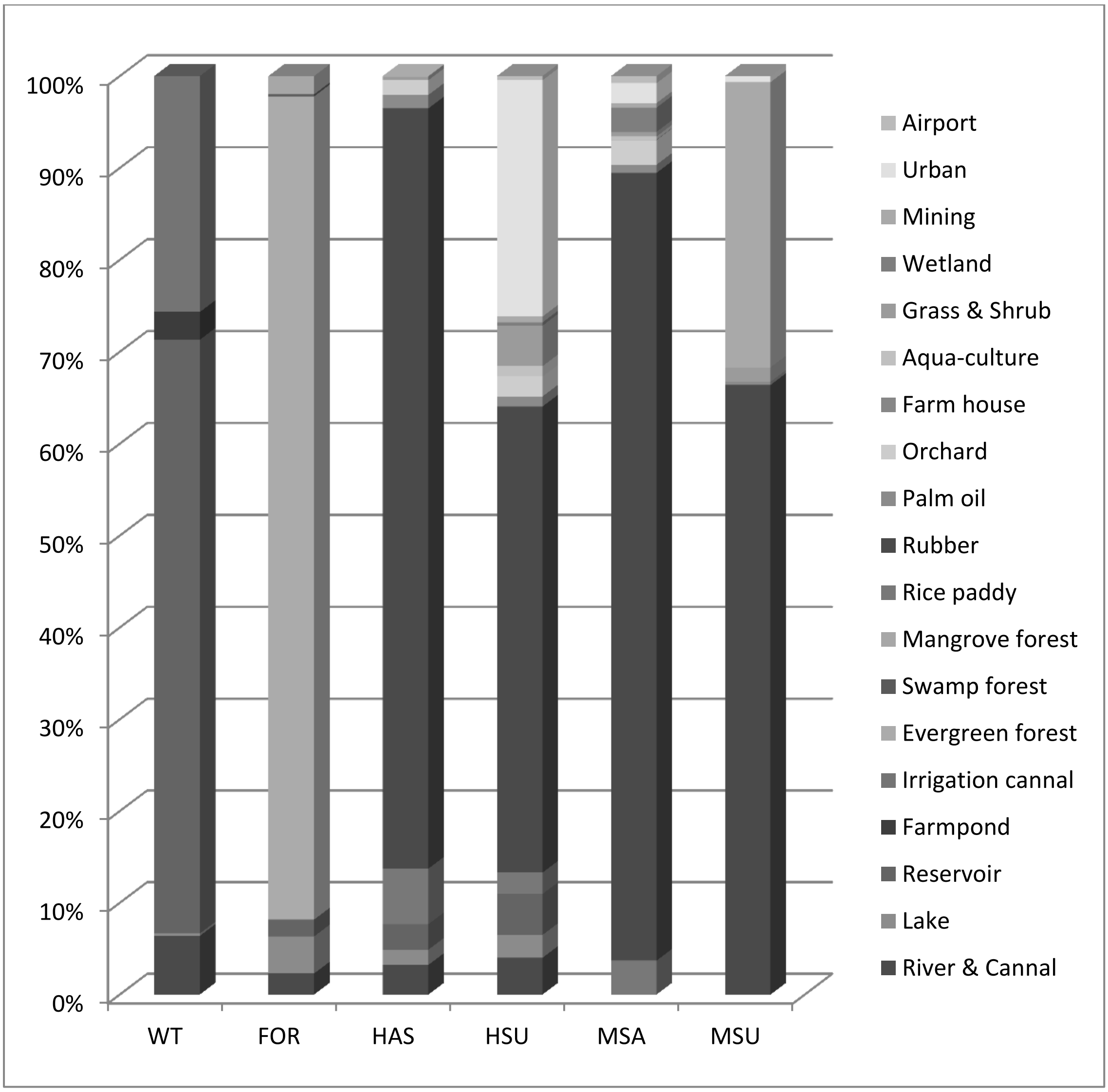


Figure 90. Land use distribution on sustainable land use planning of URB

Discussion

Careful land use planning is based on land evaluation, which is the process of assessing the suitability of land for alternative land uses. Land suitability evaluation is the process of determining the fitness of a given tract of land for a defined use (Marsh & MacAulay, 2002). In order to determine the most desirable direction for future development, the suitability for various land uses should be carefully studied with the aim of directing growth to the most appropriate sites. Considering these facts, for sustainable development of U-tapao river basin, the land use planning of basin has been developed in this study by considering the suitability analysis of leading land uses of the basin. In this study, the land use suitability maps of agriculture, forest and urban were developed by integrating multi criteria decision making (MCDM) with Geographic information Systems (GIS). So, application of the multi-criteria land suitability evaluation based on the FAO method has been adopted in the context of URB with appropriate modification. Like in most of the literatures physical land parameters were identified as most important criteria. A second important criterion was socio-economic criteria. Multi-criteria analysis was carried out through MCH process and among 13 sub criteria for agriculture and forest and 11 for urban. AHP process to calculate weight for the importance identification of the sub-criteria, consistent ratio (CR) has been maintained for reliability.

In this study, agriculture based suitability map of U-tapao river basin has been developed by using MCDM and GSI application. Since agriculture is one of the world’s most important activities’ supporting human life, the suitability analysis of agriculture is very necessary for sustainable development. U-tapao river basin is predominantly related to agricultural activities, especially rubber plantation. Therefore, in this study land use suitability of rubber was analyzed by using multi criteria technique. The whole process is broadly divided into two main factors: bio-physical and socio-economic. Since most of previous studies about land use suitability mainly focused on bio-physical aspect and gave less value on socio-economic factors, in this study socio-economic factor was also included. Actually, socio-economic also plays a crucial role in land use suitability of agriculture. So, bio-physical factor was further divided into sub-factors like climate, topography and soil and socio-economic was also divided into sub-factors like distance and livelihood. Climate aspect was further evaluated through mean temperature and annual rainfall criteria.

Analyzing the land suitability of rubber on temperature aspect, the whole basin is highly suitable for rubber whereas analyzing from annual rainfall aspect, around 86.73% land is highly or moderately suitable for rubber. The climate of the basin is suitable rubber, so most of the part of basin is covered from rubber trees. Analyzing from topography aspect, most of the part of basin is plain region, so 93.26% land is highly suitable for rubber from slope aspect whereas 86.12% land is highly suitable from elevation aspect. So, from topography point of view, the basin is also highly suitable for rubber plantation. From soil aspect, 13.71% land is highly suitable and 61.08% is moderately suitable with respect to pH value of soil; 53.87% land is highly suitable and 27.54% is moderately suitable with respect to drainage of soil; 42.37% land is highly suitable and 35.65% land is moderately suitable with respect to depth of soil; 0.23% land is highly suitable and 99.77% land is moderately suitable on nutrient availability of soil and 61.63% is highly suitable and 32.69% land is moderately suitable with respect to soil texture., Overall, most of the basin land is highly or moderately suitable for rubber plantation. From socio-economic, marketing aspect, 24.30% land is highly suitable and 25.30% land is moderately suitable for rubber from the distance from main road. Similarly, only 24.49% land is highly suitable for rubber from the distance from rubber factory. Overall, most of the land of the basin is highly or moderately suitable from marketing aspect as well. From livelihood point of view, 9.18% land is highly suitable for rubber and 63.42% land is moderately suitable for rubber with respect to population density. Similarly, 73.24% land is highly suitable and 3.78% land is moderately suitable for current available land use structure. Overall, most of the basin land is highly or moderately suitable for rubber.

Analyzing both bio-physical as well as socio-economic aspects, most of the land of the basin is either highly or moderately suitable for rubber. But, the land in basin is more suitable for bio-physical aspect rather than socio-economic aspect. In conclusion, rubber is very suitable agricultural product of the basin. For sustainable development of basin, it should be protected and definitely it will change the socio-economic status of this region. Besides rubber, other agricultural activities in the basin are very negligible. Paddy field only covers around 3.63% and remaining other agricultural activities just covers 1.61% of land. Even though the basin is suitable for other agriculture crops, the gross return from rubber is comparatively is very high, so the farmers are very interested for rubber plantation. To increase productivity, the land suitability of rubber is essential. This study is the first suitability study on rubber in the U-tapao river basin, so, it will definitely prove a landmark for land use planners as well as agriculture policy makers of southern Thailand.

Like agricultural land suitability analysis, forest land suitability has been done in many previous studies. This study also tried to find the suitable land use structure for forest by using MCDM and GIS technology. To identify appropriate criteria for suitability analysis of forest, collecting opinions from experts was used as methodology. From the experts' point of view, the suitability analysis has been done on bio-physical and socio-economic factors. With discussion with forest experts and rubber experts of southern region, the criteria for suitability analysis of rubber and forest are devised to be more or less the same because rubber is also the part of rain forest and tropical environment.

Analyzing the land use suitability of forest from climatic aspect, the whole basin is highly suitable from the average temperature criteria. From rainfall criteria, 10.19% land is highly suitable for forest, 29.03% land is moderately suitable for forest and 60.77% land is not suitable for forest. So, from rainfall aspect, not all the land of the basin is suitable for forest. From topography aspect, 93.26% land is highly suitable for forest on slope criteria whereas 90.44% land is highly suitable for forest on elevation criteria. Overall, forest land use is highly suitable for basin on topography aspect. From soil pH aspect, 51.92% land is highly suitable forest and 47.85% land is moderately suitable for forest. From soil drainage criteria, 53.87% land is highly suitable forest and 27.54% land is moderate suitable for forest. From soil depth criteria, 42.37% land is highly suitable for forest and 35.65% land is moderately suitable for forest. From soil nutrient criteria, 0.23% land is highly suitable for forest and 99.77% land is moderately suitable for forest. From soil texture criteria, 61.63% land is highly suitable for forest and 33.20% land is moderately suitable for forest. Overall, most of the land of the basin is highly or moderately suitable for forest based on soil factor. From socio-economic aspect, 25.30% land is highly suitable for forest and 25.30 % land is moderately suitable for forest based on the distance from main road criteria. Similarly, 24.60% land is highly suitable for forest and 28.64% land is moderately suitable for forest based on distance from river criteria. From population density criteria, 9.91% land is highly suitable for forest and 59.37% land is moderately suitable forest and 27.39% land is not suitable for forest. From available land use criteria, 12.87% land is highly suitable for forest, 3.78% land is moderately suitable for forest and 73.29% land is less suitable for forest and 9.80% land is not suitable for forest. Analyzing socio-economic aspect, most of the land use either is highly suitable or moderately suitable for forest. Comparing bio-physical and socio-economic criteria, the basin is highly or moderately more suitable for bio-physical aspect rather than for socio-economic aspect. Overall, 59.66% land is highly suitable and 39.50% land is moderately suitable for forest. In conclusion, the basin is highly suitable for forest, even though the forest land is less than 13% of the basin, it is possible to increase forest and increment of forest land naturally will improve environmental condition of the basin. From environmental based land use planning, reasonable amount forest land is essential and this type of suitability map of forest will help decision or policy makers to adjust appropriate policy in basin level.

Urban land use suitability analysis is not like agriculture and forest, since urban land suitability is mostly influenced from socio-economic criteria than bio-physical. Urban land suitability by nature itself is a complex process which has integrated information from different sectors like physical environments, social parameters, and economic condition of an area. In this study agriculture and forest, bio-physical and socio-economic criteria were fixed for urban land suitability analysis purpose. From climatic aspect of basin, the whole basin is moderately suitable for urban land use by considering the temperature of the basin. From rainfall criteria, 13.26% land is highly suitable and 47.51% land is moderately suitable for urban. From slope aspect, most of the land (93.26%) is highly suitable for urban and 5.72% land is moderately suitable for urban. From elevation aspect, most of the land (86.12%) is highly suitable for urban. From soil drainage condition, 38.97% land is highly suitable for urban, 3.88% is moderately suitable for urban, 16.48% land is less suitable for urban, and 40.66% land is not suitable for urban. From soil texture aspect, 28.00% land is highly suitable for urban and 30.78% land is moderately suitable for urban, 14.68% land is less suitable for urban and 26.53%. Compared with agricultural and forest land, the basin is less suitable for urban on bio-physical aspect. Based on distance from main road criteria, 24.10% land is highly suitable for urban and 25.30% land is moderately suitable. From distance from river criteria, 7.32% land is highly suitable, 39.43% land is moderately suitable, 28.64% land is less suitable and 24.60% land is not suitable for urban. From population density criteria, 1.23% land is highly suitable for urban, 26.17% is moderately suitable for urban, 63.42% land is less suitable for urban and 9.18% land is not suitable for urban. From available land use criteria, 7.97% land is highly suitable , 3.78% land is moderately suitable, 73.24% land is less suitable and 13.69% land is not suitable for urban. Even from socio-economic aspect, the basin is not so suitable for urban compared to agriculture and forest land use. So, it is recommended that the policy makers give more emphasis on agriculture and forest development and adjust current settlement with sustainable development policy.

After developing suitability maps of agriculture, forest and urban, the next step is to develop the sustainable development principle based land use planning map of the U-tapao river basin. Generally, sustainable development means the balance between economic, social and environmental aspect. The Burundtland Commission mentioned that sustainable development is development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs. So, sustainable development is based on socio-cultural development, political stability and decorum, economic growth and ecosystem protection and its main aim is to protect and enhance the environment by meeting basic human needs, promoting current and intergenerational equity and improving the quality of life of all people. Actually, implementation of sustainable development policy in practice is a very complex issue. There is always a conflict among economic, social, political, cultural and environmental issues.

In this study, the study proposed the land use planning by protecting forest and natural water resources as protected area since forest land natural water resources are in good condition, if these areas were protected, it will help to restore environment condition of the basin in the future. The basin is high potential area for tourism since beautiful and large Songkhla Lake is connected with the basin. Protecting forest and natural water resources, there is a chance of uplifting ecotourism as well as rural tourism which can uplift socio-economic aspect of local people. Since, the environment factor is one of the main components of sustainable development principle; the proposed land use planning U-tapao river basin has given high priority for water quality of river also. It was found that the converting agriculture land to urban land is one of the main causes of deteriorating water quality of river. Even urban expansion is one of causes of deteriorating condition of river, in practical ground; we could not stop the development aspect. The planning model suggested utilizing the vast waste land like grass & shrub for agriculture activities as well as urban development. It is also recommended to vertical expansion of city rather than horizontal expansion, in this process, we can utilize the land for other purposes. There is no forest in riparian zone, which is very peculiar thing in this river system. Therefore, it is highly recommended to restore forest in riparian zone which will help to control point and non-point sources pollution in river system. Another part of land use planning of URB is to manage the conflict between agriculture land and urban land; since the vast amount of agriculture land especially rubber plantation has been converting to urban land and it has been creating many socio-economic as well as environmental problems in the basin. It is very necessary to manage this problem otherwise sustainable development of the basin could not achieve in the future and how to manage this problem is also issue of decision makers of this reason. From land use planning perspective, this study has given high priority for agriculture development (especially rubber plantation), since agriculture activities are the main economic source as well as it also helps to maintain socio-cultural actives of local people. If the whole agriculture land is converted for development purpose, it might give short term benefit for economic aspect but lose social and environment aspects for long term which is out of sustainable development principle.

Giving high priority for agriculture land, the proposed land use planning systematically allocated about 70% land for agricultural purpose. In the basin, the dominating agriculture of the basin is rubber which is one of the species of rain forest. Practicing of rubber plantation in this region, it will support socioeconomic development of this region also. Rubber is high income generating cash crop and it also protect water, soil and air quality of the basin. It also supports for ecotourism as well as rural tourism in the basin. If the rubber plantation is protected like forest, the society could get multiple benefits in the future and sustainability in the basin could be achieved if we could maintain rubber dominated land for long time. Properly allocated urban land is another feature of land use planning of URB. Even urban land was given second priority after agriculture land, the study propose about 10% lands for urban development. Previously, urban development was based of encroachment of fertile agriculture and forest lands which is not good sustainable development practice. The study proposed to utilize the vast waste land for urban development without disturbing agriculture and forest lands. By utilizing this concept, economic development could be achieved without disturbing socio-environmental aspects of the basin which is main concept of sustainable development. Since, the land use planning is only the beginning phase of sustainability. Without support of other strategies planning, polices and activities; land use planning itself could not get sustainability in the basin.

Overall, by using this concept in GIS environment, the sustainable development principle based land use planning map was proposed (Fig 7.44) for URB. The total area of highly suitable land for agriculture is 281.16 km^2 (12.20%). Comparing this planning map with actual land use planning map of 2009, in this area, agricultural activities like rice paddy (17.09 km^2), rubber (231.12 km^2), palm oil (4.13 km^2) and orchard (4.54 km^2) already exist. In this zone, 0.093 km^2 of grass and shrub land and 0.23 km^2 of mining land also exist. In practice these lands can be converted to suitable agricultural land. In this zone, wet land of about 0.01 km^2 also exists, and in practice, this land can be used for supporting activities of agriculture. Similarly, in this zone, 23.947 km^2 urban lands also exist, so, it is recommended to transform this land to suitable agricultural based urban land. By adjusting these policies, a highly suitable agricultural land can be fully utilized.

The total area of highly suitable of urban is 240.51 km^2 (10.43%) and within this zone, the area of urban settlement is 81.89 km^2 and airport is 1.38 km^2. In this zone, the area of agricultural activities is 138.28 km^2. Sustainable practice of urban aspect, these can be used as urban based agricultural activities. The total area of grass and shrub land is 15.39 km^2 and this land can be used for settlement of people with modern vertical construction of buildings. This is the prime locality for urban development. The policy makers should consider this point for sustainable development of the river basin. In this zone, the area of wet land is 1.64 km^2 which can be developed as aesthetic value of urban. By implementing these concept, the highly suitable land for urban can be fully utilized.

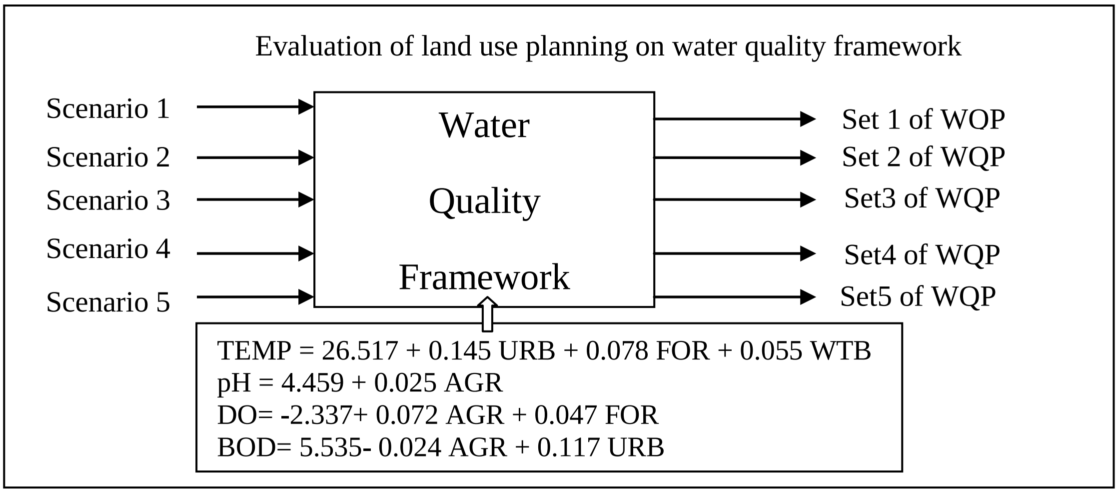
The total area of moderately suitable area for agriculture is 1461.57 km^2 (63.41%) and within this zone, agricultural activities like rice paddy (53.84 km^2), rubber (1201.34 km^2), palm oil (12.68 km^2), orchard (23.88 km^2), aquaculture (5.07 km^2) and farm house (0.83 km^2) already exist there. The grass and shrub land about 12.23 km^2 and mining land about 12.1 km^2 can be used for suitable agriculture practice. But managing settlement area of 90.56 km^2 and airport 11.21 km^2 is complex issue. So, the policy maker should focus to implement urban agriculture concept for sustainable development of river basin. The total area of moderately suitable for urban is 5.86 km^2 (0.25%) and within this zone urban settlement about 0.039 km^2 is already exists. There is agricultural land about 3.91 km^2 in this zone, so it better to convert suitable urban based agricultural land and use 0.09 km^2 grass and shrub land and 1.82 km^2 mining land for urban settlement.

Suitability analysis of land use potential is the right approach of sustainable development based land use planning in river basin level. Generally, the land is either over used or under used without considering its potential and constraints. So, suitability analysis gives the correct direction for land use policy makers. So, land evaluation is also part of the process of land use planning. The main objective of the land evaluation is the prediction of the inherent capacity of a land unit to support a specific land use for a long period of time without deterioration, in order to minimize the socio-economic and environmental costs (Baniya, 2008). In this study, for developing sustainable development based land use planning of U-tapao river basin, many factors have been considered. The main problem is to manage the changing pattern of agricultural land to non agricultural land is a great challenge for policy makers. If the land management has been done with full implementation of suitable zone of agriculture and urban, this problem can be solved. Therefore, the results of this study can lay one milestone for stakeholders to know the potentiality of land for effective land use and land management.

CHAPTER 8

DECISION MAKING

Decision making is the process of selecting the best option out of many alternatives. Decision making involves the selection of a course of action from among two or more possible alternatives in order to arrive at a solution for a given problem. In another word, decision making is the study of identifying and choosing alternatives based on the values and preferences of the decision maker. Decision making process reduces uncertainty and doubt about alternatives to allow a reasonable choice to be made from among them. Therefore, decision making can be regarded as the mental process resulting in the selection of a course of action among several alternative scenarios. The main objective of this study is to find out the best land use planning scenario map of U-tapao river basin based on water quality framework. This concept is innovative in both local and global level. Success of this concept can be replicated to other basins and to other sectors as well. In the U-tapao river basin, five types of land use planning scenario maps were developed by using multi criteria decision making (MCDM) and Geographic Information Systems (GIS).



TEMP = 26.517 + 0.145 URB + 0.078 FOR + 0.055 WTB
pH = 4.459 + 0.025 AGR
DO= -2.337+ 0.072 AGR + 0.047 FOR
BOD= 5.535- 0.024 AGR + 0.117 URB

*Figure91.*DecisionMakingFramework

Scenario 1

The first scenario is actual land use structure of U-tapao river basin of 2009. The total area of the basin is about 2305.00 km^2, the area of agricultural land is 1696.71 km^2 (73.62%), forest land is 296.52 km^2 (12.86%), urban land is 209.06 km^2 (9.07%) and water body is 102.57 km^2 (4.45%). The agricultural land is the dominating land use of the basin especially rubber trees which covers the area of about 1513.69 km^2 (65.67%). Other major agricultural practices like rice paddy covers area about 103.73 km^2 (4.50%) and orchard which covers area about 30.42 km^2 (1.32%). In the case of forest, the area of evergreen forest is 294.21 km^2, disturbed forest area is 1.99 km^2 and planted forest area is 0.32 km^2. In the case of urban land, the area of city, town and commercial land is 180.60 km^2, village area is 85.89 km^2, institutional land is 26.10 km^2, transportation land is 19.77 km^2 and recreation land like golf course is 5.53 km^2. In the case of water body, the area of natural resources like lakes and rivers is 7.24 km^2, the area of artificial reservoir is 17.25 km^2, area of grass and shrub land is 85.77 km^2, wet land is 6.38 km^2 and mining land is 8.11 km^2. The land use planning scenario map is given below.

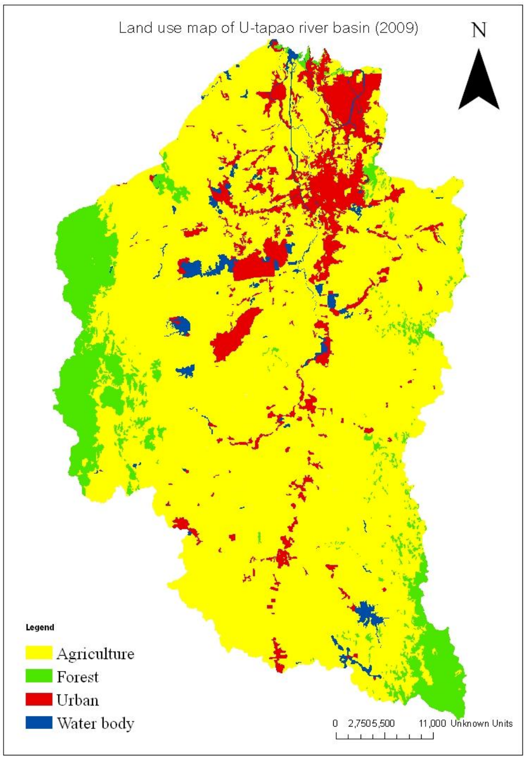


Figure 92. Scenario1 map of land use planning of URB

Scenario 2

The second scenario is the proposed planning map of U-tapao river basin. It was prepared by fixing the water body (rivers, lakes and reservoirs) and forest land use and allocating the agricultural and urban land in suitability sites. This map was prepared on priority basis; the first priority was given to highly suitable land of agriculture and second priority was given to highly suitable urban land. Similarly, priority was set for moderate and less land use structure (Priority ranking: highly suitable for agriculture> highly suitable for urban> moderate suitable for agriculture> moderate suitable for urban>less suitable for agriculture>less suitable for urban). Total agricultural land is 1765.78 km^2 (76.62%) including highly suitable for agriculture land 304.21 km^2 (13.20%) and moderately suitable land for agriculture 1461.57 km^2 (63.41%). The total urban land is 223.32 km^2 (9.69%) including highly suitable urban land 217.46 km^2 (9.43%) and moderate suitable urban land 5.86 km^2 (0.26%). The area of forest land is 296.52 km^2 (12.86%) and water body is 19.38 km^2 (0.83%).

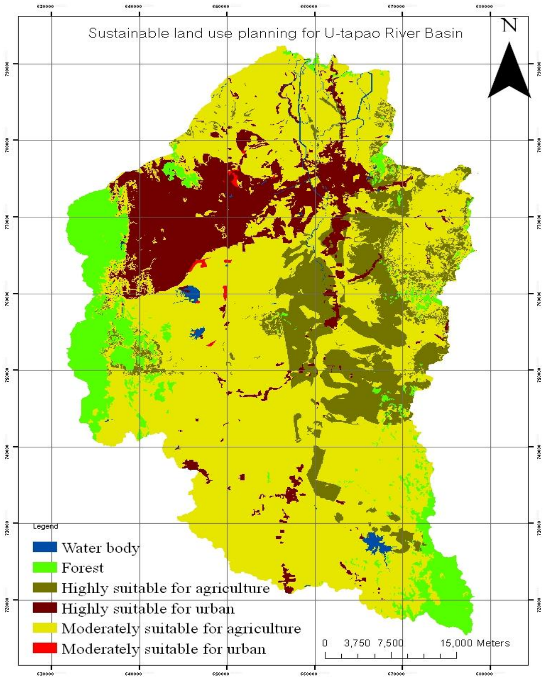


Figure 93. Scenario 2 map of land use planning of URB

Scenario 3

This third scenario was developed by giving high priority on forest land use. On this planning, first priority was given to highly suitable land for forest followed highly suitable land for agriculture and followed by highly suitable land for urban. Similarly, high priority was given to moderately suitable land and less suitable lands (Ranking of priority: highly suitable land for forest, highly suitable land for agriculture, highly suitable land for urban, moderately suitable land for forest, moderately suitable land for agriculture, moderately suitable land for urban, less suitable land for forest, less suitable land for agriculture, less suitable land for urban).

During analysis of this process, the total area of forest land is 2046.67 km^2 (88.79%) including highly suitable land for forest about area 1407.83 km^2 (61.08%) and moderately suitable forest area 638.84 km^2 (27.71%). The total area of agricultural land is 76.42 km^2 (3.32%) and the total area of urban is 162.67 km^2 (7.06%). The total area of water body is 19.24 km^2 (0.83%).

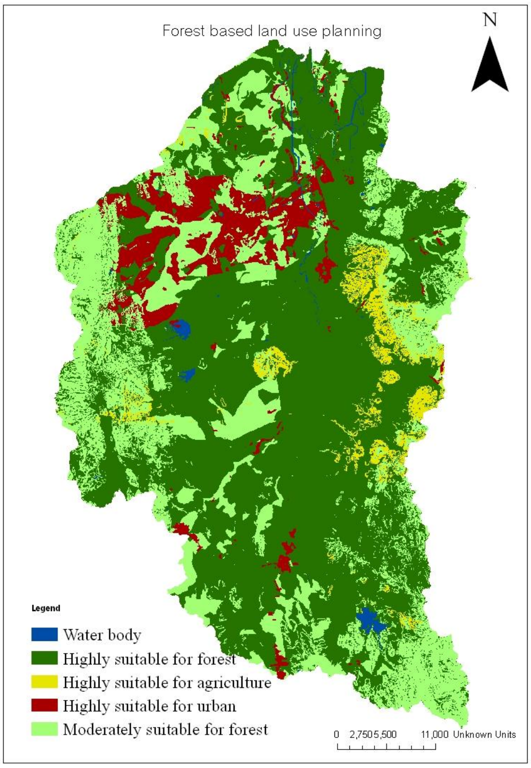


Figure 94. Scenario 3 map of land use planning of URB

Scenario 4

The fourth scenario was developed by giving high priority to agriculture. In this planning process, the first priority was given to highly suitable land for agriculture, followed by highly suitable land for forest followed by highly suitable land for urban. Similarly, moderate and less suitable land use for same ranking process was implemented (Priority ranking: highly suitable land for agriculture, highly suitable land for forest, highly suitable land for urban, moderately suitable land for agriculture, moderately suitable land for forest, moderately suitable land for urban, less suitable land for agriculture, less suitable land for forest, less suitable land for urban). The total area of agriculture is 845.71 km^2 (36.69%) including highly suitable area for agriculture about 259.09 km^2 (11.25%) and moderately suitable area of agriculture 586.62 km^2(25.44%). The total area of forest is 1228.79 (53.31%) including highly suitable area for forest 1223.49 km^2 (53.08%) and moderately suitable area for forest 5.30 km^2 (0.23%). The total area of urban land as highly suitable for urban land is 211.37 km^2 (9.17%). The total area of water body is 19.13 km^2 (0.83%).

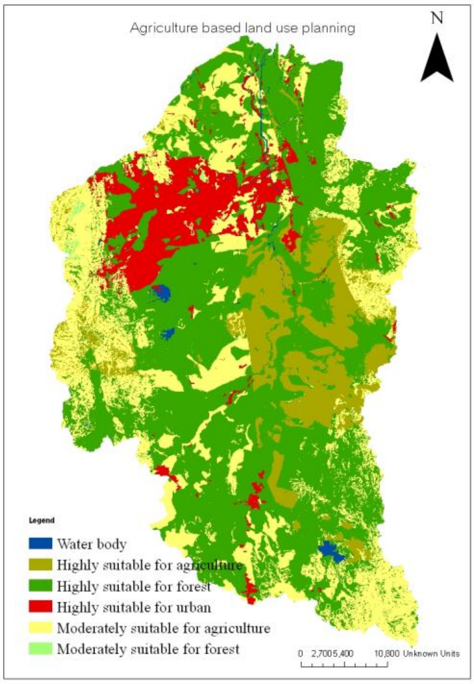


Figure 95. Scenario 4 map land use planning of URB

Scenario 5

The fifth scenario was developed by giving high priority to urban. In this planning process, the first priority was given to highly suitable land for urban, followed by highly suitable land for forest followed by that highly suitable land for agriculture. Similarly, moderate and less suitable land use for same ranking process was implemented (Priority ranking: highly suitable land for urban, highly suitable land for forest, highly suitable land for agriculture, moderately suitable land for urban, moderately suitable land for forest, moderately suitable land for agriculture, less suitable land for urban, less suitable land for forest, less suitable land for agriculture). The total area of urban land is about 815.99 km^2 (35.40%) including highly suitable area is 292.53 km^2 (12.69%) and moderately suitable area is 523.46 km^2 (22.72%). The total area of forest is 1420.33 km^2(61.62%) including highly suitable area 1365.71 km^2(59.25%) and moderately suitable area is 54.62 km^2(2.37%). The total area of agriculture is 49.55 km^2(2.15%) and water body is 19.13 km^2(0.83%).

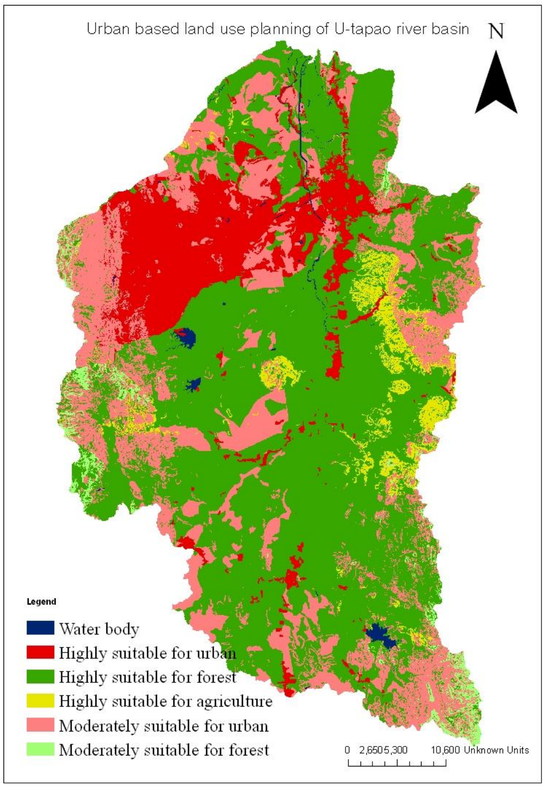


Figure 96. Scenario 5 map of land use planning of URB

Decision Making

In fact, evaluation of land use planning map is a very complex and difficult task. For this, highly skilled experts in this area are needed. Generally, land use planning maps are evaluated on subjective basis and experts having huge experience on this area, evaluate the planning map. The main drawback of this approach is the difficulty to reach to the pin-point conclusion. Also, decision-making by subjective process is not free of bias, as the perception regarding a problem can diverge from person to person. One cannot expect a decision maker or an expert to be highly consistent while dealing with such a subjective process. To overcome this problem, many objective based methods are used in evaluation process but most of the methods are just concentrated on socio-economic aspects. Therefore, it is necessary to develop effective decision making tool to evaluate the land use planning map by considering environmental aspect. This study mainly focused to develop a decision making tool to evaluate the land use planning map of the river basin based on water quality framework. This approach is very new and has been implemented to U-tapao river basin for the first time. To evaluate the land use planning, five scenario maps were prepared as explained above. The decision matrix of the evaluation is given on Table 27.

During evaluation process, the five scenario maps were constructed by using GIS technology and the area of land uses of the corresponding scenario maps are presented in table 27. In the scenario map of I and II, the dominating land use is agriculture whereas for scenario maps of III, IV and V, the dominating land use is forest. As mentioned already, in regression models of predicting water quality parameters, dependent variables were water quality and independent variables were the percentage of land uses. Analyzing every aspect, the four predicative models of water quality parameters (TEMP, pH, DO and BOD) were established in U-tapao river basin on linking process of land use and water quality parameters. Putting the corresponding values of land use of five scenario maps as independent variables on regression equations (i, ii, iii & iv), the expected values of water quality parameters are presented in Table 27.

Analyzing scenario map I, the expected TEMP was 29.07 ^{0}C which is more or less the average water temperature of URB (28.72 ^{0}C). The expected pH value of scenario I was 6.29 and the average pH value of URB was 6.82. Similarly, the expected DO of scenario I was 3.56 mg/L and the expected DO of scenario which is slightly less than average value of DO of URB (4.16 mg/L) and the expected BOD was 4.82 mg/L which is slightly higher than the average value of BOD of URB 3.37 mg/L. Similarly, the expected values of TEMP, pH, DO and BOD were generated from regression equations of remaining four scenario and these values are presented in Table 27.

From water quality aspect, the relatively lower temperature is good for water quality of the river. From table 8.1, the lowest temperature 28.97 ^{0}C was generated from the scenario map II. In the case of pH, values below 7.0 indicate acidity level of water. In this case, lower pH value is not good for U-tapao river, so the highest pH value which is 6.37 was generated from scenario map II. In the case of DO, higher DO value indicates the abundance of oxygen in water which is necessary for aquatic life. The highest DO value, 3.78 mg/L was generated from scenario map II. In the case of BOD, lower value of BOD indicates the higher water quality status, the lowest value of BOD, 4.82 mg/L was generated from scenario map I as well as scenario map II. So, land use structure scenario map I reduces the value of BOD whereas scenario map II increase the value of DO and pH and also reduced the value of BOD. Overall, the scenario map II is good for the land use planning from water quality aspect.

Therefore, this study successfully demonstrated the utilization of decision making method to evaluate land use planning map. It is concluded that evaluation of land use planning map before implementation is very important and also useful for sustainable development of river basin.

Table 27
Decision matrix of evaluating land use planning maps.

Scenario	Area of land use (in %)				Water quality parameters of URB			
	AGR	FOR	URB	WTB	TEMP	pH	DO	BOD
I	73.62	12.86	9.07	4.45	29.07998	6.2995	3.56806	**4.82931**
II	76.62	12.86	9.69	0.83	**28.97078**	**6.3745**	**3.78406**	4.82985
III	3.32	88.79	7.06	0.83	34.51197	4.5420	2.07517	6.28134
IV	36.69	53.31	9.17	0.83	32.05048	5.37625	2.81025	5.72733
V	2.15	61.62	35.40	0.83	36.50201	4.51275	2.10714	9.6608

CHAPTER 9

CONCLUSIONS AND RECOMMENDATION

Conclusions

U-tapao river has been polluted because of various factors over the last ten years and its downstream portion is more polluted compared to the upstream. Among the factors that polluted the river, the most important ones are; rapid urban and industrial expansions, domestic and industrial waste discharge into the river and non point sources pollution such as surface runoff. As per the current water quality standards, the water quality of U-tapao river does not meet the drinking water quality standard of Thailand as well as World Health Organization (WHO) standard and water cannot be used for domestic purpose without treatment. Even the status of water quality of U-tapao river is slightly polluted, it is not out of control from surface water quality management aspect. Awareness program on environmental issues, public participatory approach in decision making, promotion of appropriate management practices, and modification of land use are among the methods that could be implemented to reduce point and non-point sources of pollution.

Analyzing seasonal variation of water quality parameters, TEMP, pH, TUR, NH_3 and FCB showed significant seasonal variation. Analyzing the spatial and annual variations, TEMP and DO showed significant spatial variation whereas pH, BOD, EC, TUR and NH_3 showed significant annual variation. TEMP was found to be the most sensitive water quality parameter in all types of variation analysis. So, this type of understanding of variation of water quality parameters helps the planner to select appropriate parameters for effective evaluation and monitoring system of river

From correlation analysis of land use with water quality parameters, the agricultural land did not show any positive relationship with pollutants whereas urban land had positive correlation with pollutants. The results of this study indicated that converting agriculture land to urban land might be one of the causes of increasing non point source pollution in the river system. In this study, four predicative models for water quality parameters (TEMP, pH, DO, and BOD) have been successively established in the basin level by using multiple regression analysis. These models could help to generalize the impact of land use patterns on water quality and evaluation of the status of river on changing pattern of lands in the basin.

From land use perspective, the dominating land use of the basin is agriculture especially rubber trees, which cover most parts of the basin. Regarding the forest, during a decade period, the area of forest land has increased in a significant manner indicating the good reforestation activities in the basin. On the other hand, urban land use and water body have also increased rapidly; but agricultural land has been decreasing and mostly converted to urban land. From land use management aspect, the change of fertile land to urban land is the main problem of the basin.

For sustainable development, the land resources of river basin should be utilized in proper order. On this regard, this study evaluated the land use resources of agriculture, forest and urban of the basin. On this process, this study generated land use suitability maps of agriculture (rubber), forest and urban by using concept of MCDM in GIS environment. In suitability analysis, socio-economic factors like livelihood and distance from road and river were included with bio-physical factors. Analyzing the suitability land uses of the basin, most of the land of the basin is highly or moderately suitable for all types of land use like agriculture, forest and urban. Rubber is the most dominating and important crop for sustainable development of this region. Due to various reasons, the area of rubber has been decreasing from last decade and it is a very important issue of sustainable development of this region. In this region, farmers are getting high benefit from rubber plantation and rubber is also supporting to maintain greenery of the basin. This study found that the rubber is associated with improved water quality of river. From all these aspects, the study strongly suggests to protect rubber trees for agriculture purpose and make local farmers aware of the importance of rubber for sustainable development of this region.

Generally, scenario analysis concept is popular land use planning. In this study, different types of scenario land use planning maps were generated by using suitability analysis concept of land use in GIS environment. Evaluation of the best land use planning scenario is a challenging issue for land use planners. To overcome this difficulty, the study forwarded the evaluation methodology to select the best land use planning on water quality framework. By using this concept, the sustainable development principle based land use planning scenario map was the best on water quality framework. The study showed that 76.62% of agriculture land, 12.86% of forest land, 9.69% of urban land and 0.83% of water body is an ideal land use structure of the basin regarding water quality aspect.

The concept of evaluation of land use planning on water quality framework is simple as well as practical and it can be easily used by the land use planners of river basin and Lake Basin management. With slight modification of original concept, the local as well as regional planners can use this concept to evaluate their regular land use planning maps. Besides these, the concept of this study is very useful for those academic researchers who are interested to link land use with water quality parameters and land use planning. The concept of evaluation land use planning of the basin on water quality framework can be replicated to other sectors with similar background.

Recommendations

This study used secondary data that has the possibility of bias and limits the generalization of study findings. It is recommended to collect the primary data of water quality and land use information from remote sensing approach. After that, the relationship of land use and water quality can be established. It is also recommended to use more than 10 years data of water quality and land use information. To evaluate spatial and temporal variations of water quality parameters, multivariate statistical techniques like cluster analysis, factor analysis and principal component analysis are recommended.

To adjust the relationship between land use and water quality, it is recommended to adjust more water quality variables and a huge data set of land use and water quality parameters. To increase predicative power of regression models, it is recommended to adjust water quality related factors like hydrology, climate and even socio-economic factors as independent variables. For future research, the regression models should be re-evaluated, in this study, only the data of 2000 to 2008 were used to run the model and the data of the year 2009 were used to test the model. It is recommended to use the data of the year 2000 to 2010 to run the model and the data of the year 2011 and 2012 to test the model. It is also recommended to evaluate the model every year by adjusting the new annual data of land uses and water quality parameters. It is also recommended to perform sensitivity analysis by using Monte Carlo Method.

Besides regression models, artificial neural networking (ANN) approach as well as factor analysis/ principal component analysis might be useful to link land uses with water quality. It is also recommended to link land uses with water quality in full basin as well as buffer zone spatial scales. Since this study only linked land uses of level 1 category with water quality, it is recommended to link land uses of level 2 or level 3 with water quality by adjusting more data of the year 2010, 2011 and 2012.

In this study, to analyze the land use suitability of agriculture, forest and urban, only limited bio-physical and socio-economic factors were selected. It is recommended to add more socio-economic factors like land tenure, the price of land etc for analysis purpose. In this study, for the purpose weighting factors, only experts' opinions were counted. It is recommended to use public opinion for weighting different factors by using survey method. It is recommended to use Fuzzy set theory concept for rating and scaling of factors and co-factors.

In this study, only land suitability analysis of level 1 land use category like agriculture, forest and urban has been done. It is recommended to do land suitability analysis of level 2 or 3 categories. It is recommended to use multi objectives decision making approach for land use planning of U-tapao river basin by considering economic, social and environmental factors of the basin.

In this study, only limited aspects of sustainable principle was done for land use planning. It is recommended to adjust more variables of social (equity, health, education, good governance etc), economic (gross domestic product, per capita income etc) and environment (air quality, climate change, bio diversity etc.) for further land use planning.

In this study, land use planning scenario maps were generated by using GIS technology. It is recommended to develop various land use planning scenario maps by utilizing participatory approach. This study tried to develop the evaluation of land use planning on water quality framework. Using similar concept, it is recommended to develop the evaluation of land use planning on air quality framework, sustainable development framework, biodiversity framework, and ecological framework.

Limitations of study

- Secondary data of water quality were collected from Regional Environmental Office-16, Songkhla and Land use information of the basin were derived by using GIS application on the maps provided by Land development department, Thailand. The reliability and validity of data of water quality and land uses were not evaluated or cross checked considering the reputation of both organizations.
- Division of land use planning, Department of land use survey, Thailand classified land uses into three levels. In this study, only the land uses of level 1 were used to link with water quality parameters since most of land uses of level 2 &3 didn't show the significant relationship with water quality parameters.
- In this study, sub-watershed spatial scale was used. The percentage of land uses (annual) of ten watersheds were linked with the annual average water quality data of ten corresponding monitoring stations of river.
- Besides other methods of linking of land uses with water quality, correlation and regression analysis were used to find the relationship of land uses and water quality of river. For the case of regression analysis, in this study, multiple regression analysis was used. Only land use variable (Agriculture, Forest, Urban and Water body) was used to predict water quality by keeping other influencing variable as constant or excluded from analysis. Due to multicolineartiy effect, only maximum three predictors were used to explain water quality. For evaluation of regression models, only longitudinal evaluation approach was used.

- In this study, for land suitability analysis, the land uses of level 1 (Agriculture, Forest and Urban) were only analyzed by using MCDM concept in GIS environment. For the land suitability analysis of agriculture, only suitability analysis of rubber has been done.
- For land suitability analysis, only two factors, namely, bio-physical (topography, soil and climate) and socio-economic (distance and livelihood) were considered. During selection and evaluation of the factors and co-factors of land use suitability analysis, only opinions of experts of related field were considered. Factors and co-factors were scaled and rated on the basis of literature survey, experts' opinion and availability of data. To assign weight for factors and co-factors, AHP with experts' opinion approach was used.
- In this study, for allocation of land uses of agriculture, forest, urban and water body, subjective approach like priority ranking was used. Bio-physical factor was given more priority rather than socio-economic factor in land use suitability analysis and environmental factor was given high priority for sustainable development of river basin.
- In this study, for land use planning for sustainable development of river basin, only protection of forest and natural water resources and water quality of river was considered for environmental aspect and allocating land resources for agriculture and urban for socio-economic development of the basin.
- Only the water quality framework of river was used to evaluate the land use planning of river U-tapao river basin.

Future Research

- Linkage of land use of the basin with water quality parameters with circular buffer zone approach
- Establish the predicative models of water quality parameters by adjusting climate, hydrological and socio-economic factors with land use structure of the basin
- Land use suitability analysis of agriculture, forest an urban in large scale as Songkhla lake basin
- Developing land use planning map by using public participatory approach

  Developing decision making supporting tool to evaluate land use planning on sustainable development framework

REFERENCES

Adamu, M., & Nabegu, A. B. (2011). Surface water pollution source identification using principal component and factor analysis in Getsi River, Kano, Nigeria. *Australian Journal of Basic and Applied Science, 5*(12), 1507-1512.

Adekunle, A., & Eniola, T. (2010). Impact of industrial effluents on quality of segment of Asa River within an industrial estate in Ilorin, Nigeria. *New York Science Journal, 1*(1), 17-21.

Ahearn, D. S., Richard, W. S., Randy, A. D., Michael, D., Joshua, J., & Kenneath, W. T. (2005). Land use and land cover influence on water quality in the last free-flowing river draining westerm Sierra Nevada, California. *Journal of Hydrology, 315*, 234-247.

Alkharabshs, A., & Taanay, R. (2003). Influence of urbanization on water quality deterioration during drought periods at South Jordon. *Journal of Arid Environments, 53*, 619-638.

Amirii, B. J., & Namane, K. (2008). Entire catchment and buffer zone approaches to modeling linkage between river water quality and land cover: A case study of Yamaguchi prefecture, Japan. *China Geography Science, 1*, 05-092.

Arnold, J. C. L., & Gibbons, C. J. (1996). Impervious surface coverage. *Journal of the American Planning Association*, *62*, 243-258.

Attua, E. M. (2008). Using multiplelinear regression techniques to quantify carbon stocks of fallow vegetation in the tropics. *West African Journal of Applied Ecology, 12*.

Azyana, Y., & Norulaini, N. A. (2012). The entire catchment and site buffer radii landscale variables, urban land use as predictors of water quality variation. *International Journal of Environmental Science and Development, 3*(2), 141-145.

Baer, W. C. (1997). General plan evaluation criteria: An approach to making better plans. *Journal of the American Planning Association*, 63(3): 329-345.

Bagalwa, M. (2006). The impact of land use on water quality of the Lwiro River, Democratic Republic of Congo, Central Africa. *African Journal of Aquatic Science, 3*(1), 137-143.

Bahar, M. M., Ohmori, H., & Hamamuro, M. (2008). Relationship between river water quality and land use in a small river basin running through the urbanizing area of central Japan. *Limnology*, 9,19-26.

Baker, J. P., Hulse, D. W., Gregory, S. V., White, D., Sickle, J. V., Berger, P. A., Dole, D., & Schumaker, N. H. (2004). Alternative futures for the Willamette River Basin, Oregon. *Ecological Applications*, *14*(2), 313-324.

Banadda, E. N., Kansiime, F., Kogobe, M., Kizza, M., & Nhapi, I. (2009). Landuse-based nonpoint source pollution: A threat to water quality in murchison bay, Uganda. *Water Policy*, *11*(1), 94-105.

Bandyopadhyay, S., Jaiswal, R. K., Hegde, V. S., & Jayaraman, V. (2009). Assessment of land suitability potentials for agriculture using a remote sensing and GIS based approach. *International Journal of Remote Sensing, 30*, 879-895.

Baniya, N. (2008). *Land suitability evaluation using GIS for vegetable crops in Kathmandu valley/ Nepal.* PhD, Humboldt University of Berlin, Germany.

Basnyat, P., Teeter, L. D., Flynn, K. M., & Lockaby, B. G. (1999). Relationhsips between landscape characteristics and nonpoint source pollution inputs to coastal estuaries. *Environmental Management, 23*(4), 539-549.

Basnyat, P., Teeter, L. D., Lockaby, B. G., & Flynn, K. M. (2000). The use of remote sensing and GIS in watershed level analysis of non-point source pollution problems. *Forest Ecology and Management*, *128*, 65-73.

Bennui, A., Rattanamanee, P., Puetpaiboon, U., Phukpattaranont, P., & Chetpattananondth, K. (2007). *Site selection for large wind turbine using GIS*. Paper presented at the PSU-UNS International Conference on Engineering and Environment - ICEE-2007, Phuket

Berke, P. & Goschalk, D. (2009). Searching for the Good Plan A Meta-Analysis of Plan Quality Studies. *Journal of Planning Literature*, 23(3), 227-240.

Berke, P. R., & Manta-Conroy, M. (2000). Are we planning for sustainable development? An evaluation of 30 comprehensive plans. *Journal of the American Planning Association*, 66 (1), 21-33.

Berke, P. R., Dixon, J., & Eriksen, N. (1997). Coercive and cooperative intergovernmental mandates: A comparative analysis of Florida and New Zealand environmental plans. *Environment and Planning B: Planning and Design,*24, 451-68.

Berke, P., & Goodschalk, D. (2009). Searching for the Good Plan, A Meta-Analysis of Plan Quality Studies. *Journal of Planning Literature*, 23(3), 227-240.

Bhatta, R. P., & Khanal, S. N. (2011). Impoundment after damming the rivers changes in flow regime and effect in water quality of chilime hydropowr project in Rawuwa District Nepal. *Advances in Bioresearch, 2*(1), 33-39.

Biswas, A. K. (2004). Integrated water resources management: a reassessment. *Water International*, 29, 248-256.

Bledsoe, B. P., & Watson, C. C. (2001). Effects of urbanization on channel instability. *Journal of the American Water Resources Association, 37*, 255-270.

Boonyanuphap J, Det W, Kasutoshi S (2004) GIS-based land suitability assessment for Musa (ABB-group) plantation. *Journal of Applied Horticulture, 6*, 3-10.

Braskerud, B. C. (2002). Factors affecting phosphorous retention in small constructed wetlands treating agricultural non-point source pollution. *Ecological Engineering, 19*, 41-61.

Brody, S. (2003). Are we learning to make better plans? A longitudinal analysis of plan quality associated with natural hazards. *Journal of Planning Education and Research*, 23(2), 191-201.

Brody, S. (2003). Implementing the principles of ecosystem management through local land use planning. *Population and Environment*, 29 (6), 511-40.

Brundtland, C. (1987). Our commong future, World commission on environmental and development, UN commission on sustainable development: UN.

Burby, R. J., May P. J., Berke, P. R., Dalton, L. C., French, S. P., & Kaiser, E. J. (1997). Making Governments Plan: State Experiments in Managing Land Use. Baltimore, MD: Johns Hopkins University Press.

Callender, E., & Rice, K. C. (2000). The urban environmental gradient: Anthropogenic influences on the spatial and temporal distributions of lead and zinc in sediments. *Environmental Science & Technology, 34*, 232-238.

Carpenter, S. R., Caraco, N. E., Correl, D. L., Howarth, R. W., & Smith, V. H. (1998). Nonpoint pollution of surface water with phosphorus and nitrogen. *Ecological ical Applications, 8*(3), 559-568.

Ceballos-Silva, A., & Lopez, B. J. (2003). Delineation of suitable areas for crops using a multi-criteria evaluation approach and land use/cover mapping: A case study in central Mexico. *Agricultural Systems, 77*(2), 117-136.

Ceballos-Silva A, & López-Blanco J. (2003). Evaluating biophysical variables to identify suitable areas for oat in Central Mexico: a multi-criteria and GIS approach. *Agriculture, Ecosystems and Environment*, 95, 371–377.

Chakhar, S., & Mousseau, V. (2008). GIS-based multi-criteria spatial modeling generic framework. *International Journal of Geographical Information Science, 22*, 1159-1196.

Chakrabarty, B. K. (2001). Urban management, concept, principles, techniques and education. *Cities, 18*(5), 331-345.

Changnon, S. A., & Demissie, M. (1996). Detection of changes in stream flow and floods resulting from climate fluctuations and land use drainage changes. *Climatic Change, 32*, 411-421.

Chen, C. H., Liu, W. L., Liaw, S.L., & Yu, C.H. (2005). Development of a dynamic strategy planning theory and system for sustainable river basin land use management. *Science of the Total Environment*, 346, 17-37.

Chenini, I., & Khmiri, S. (2009). Evaluation of ground water quality using multiple linear regression and structural equation modeling. *International Journal of Environment Science and Technology, 6*(3), 509-519.

Cheson, S. & Lim, A. (2008). Forecasting fish catches in the Songkhla Lake basin. *ScienceAsia*, 34: 335-340

Chinea, D., & Helmer, E. (2003). Diversity and composition of moist and wet secondary forests of Puerto Rico: Analysis of the 1990 forest inventory. *Forest Ecology and Management, 180*, 227-240.

Christodoulou, C., & Nakos, G. (1990). An approach to comprehensive land use planning. *Journal of Environmental Management, 31*, 39-46.

Clausen, J. C., & Meals, D. W. (1989). Water quality achievable with agricultural best management practices. *Journal of Soil and Water Conservation*, 593-596.

Clinton, B. D., & Vose, J. M. (2006). Variation in stream water quality in an urban headwater stream in the southerm appalachians. *Water, Air, and Soil Pollution, 169*, 331-353.

Conacher, A., & Conacher, J. (2000). *Environmental Planning and Management in Australia*, South Melboourne, Oxford University Press.

Crawford, D. (1994). Using remotely sensed data in landscape visual quality assessment. *Landscape and Urban Planning, 30(1-2)*, 71-81.

Cruz, R. B. (2006). Land Use Information System for local government: The tase of Naga City, Philippines. *Systemics, Cybernetics and Informatics,* 4(6), 67-73.

Daniel, M. (2002). Effects of urban sewage on dissolved oxygen, dissolved inorganic and organic carbon, and electrical conductivity of small streams along a gradient of urbanization in the piracicaba river basin. *Water, Air, and Soil Pollution, 136*, 189-206.

Davis, M. L., & Masten, S. J. (2004). *Principles of Environmental Engineering and Science*: McGraw Hill: International.

Deng, X., Huang, J., Rozelle, S., & Uchida, E. (2008). Growth, population and industrialization and urban land expansion of China. *Journal of Urban Economics, 63*, 96-115.

Drobne, S., & Lisec, A. (2009). Multi-attribute decision analysis in GIS: Weighted linear combination and ordered weighted avaraging. *Informatica, 33*, 459-474.

Duh, J. D., Shandas, V., Chang, H., & Georg, L. A. (2008). Rates of urbanization and the resiliency of air and water quality. *Science of the Total Environment, 400,* 238-256.

Duong, T. T., Coste, M., Feurter-Mazel, A., Dang, D. K., Gold, C., Park, Y. S., & Boudou, A. (2006). Impact of urban pollution from the Hanoi area on benthic diatom communities collected from the red Nhue and Tolich rivers (Vietnam). *Hydrobioligia, 563*, 201-216.

Eastman, R., Weigen, J., Peter A. K., & James, T. (1995). Raster Procedure for Multi–Criteria/Muti-Objective Decisions: *Photogrammetric Engineering & Remote Sensing*, 61(5), 539-547.

Edwards, M. M., & Haines, A. (2007). Evaluation smart growth: Implications for small communities. *Journal of Planning and Research*, 27(1), 49-64.

Elzabeth, N. & Machiwa, J. F. (2004). The influence of land-use patterns in the Ruvu river watershed on water quality in the river system. *Physics, Chemistry of the Earth, 29,* 1161-1166.

Elzabeth, N., & Machiwa, J. F. (2004). The influence of land-use patterns in the Ruvu river watershed on water quality in the river system. *Physics, Chemistry of the Earth, 29*, 1161-1166.

Emmerth, P. P., & Bayne, D. R. (1996). Urban influence on phosphorous and sediment loading of west point lake, Gergia. *Water Resource Bulletin, 32,* 145-154.

Eni, D. A., Obiefuna, J. N., Oko, C., & Ekwok, I. (2011). Impact of urbanization on sub-surface water quality in Calabar municipality, Nigeria. *International Journal of Humanities and Social Science, 1*(10), 167-172.

Erickson, D. (1995). Rural land use and land cover change: Implications for local planning in the river raisin watershed. *Land Use Policy, 12*(3), 223-236.

Even, S., Poulin, M., Mouchel, J. M., Seidl, M., & Servais, P. (2004). Modeling oxygen deficits in the seine river downstream of combined sewer overflows. *Ecological Modelling, 173*, 177-196.

Eydrane, E., Ozdemir, T., & Alarslan, E. (2005). Importance of diagnostic in multiple regression analysis *Journal of Applied Science, 8*(10), 1792-1796.

Fafchamps, M., & Quisumbing, A. R. (2002). Control and ownership and ownership of assets within rural Ethiopian households. *Journal of Development Studies, 38*(6), 47-82.

Fennell, D. A., & Dowling, R. K. (2003). *Ecotourism Policy and Planning*: CABI: UK.

Ferrier, R. C., Edward, A. C., Hirst, D., Littlewood, I. G., Walts, C. D., & Morris, R. (2001). Water quality of Scottish rivers: Spatial and temporal trends. *The Science of the Total Environment, 265*, 327-342.

Filik Iscen, C., Emiroglu, O., Ilhan, S., Arslan, N., Yilmaz, V., & Ahiska, S. (2008). Application of multivariate statistical techniques in the assessment of surface water quality in Uluabat Lake, Turkey. *Environmental Monitoring and Assessment*, 144: 269-276.

Finkenbine, J. K., Atwater, J. W., & Mavinic, D. S. (2000). Stream health after urbanization. *Journal of the American Water Resources Association, 36,* 1149-1160.

Fisher, D. S., Steiner, J. L., & Wilkinson, S. R. (2000). The relationship of land use practices to surface water quality in the upper oconee watershed of Gergia *Forest Ecology and Management, 128*, 39-48.

Florent, J., Marius, T., & Andre, M. (2001). Using GIS and outranking multi-criteria analysis for land-use suitability assessment. *International Journal of Geographical Information Science, 15*, 153-174.

Food & Agriculture Organization [FAO] (1976). A framework for land evaluation: Soils Bulletin 32, Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO] (1984a). Land evaluation for forestry, forestry paper 48: Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO] (1984b). Land evaluation: Technical report 5, Part III. Crop environmental requirements; Report prepared for the Government of Ethiopia by FAO acting as executing agency for the UNDP, Rome, Italy.

Food & Agriculture Organization [FAO] (1986). Land evaluation for development: Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO] (1990). Guidelines for soil profile description: Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO] (1991). Guidelines: land evaluation for extensive grazing: Soils Bulletin 58, Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO] (1993). An international framework for evaluating sustainable land management (FESLM): Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO] (1993). Guidelines for land use planning. FAO Development Series 1, Vol. 8(96), Food and Agricultural Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO] (1995). Programme for the World census of agriculture 2000: FAO Statistical Development Series No.5, Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO] (1995). Planning for sustainable use of land resources: Towards a new approach: Land and Water Bulletin 2, Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO] (1995). The Future of our land: Facing the challenges. Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO] (1996). Agro-ecological zoning, guidelines: FAO Soils Bulletin 73. Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO] and United Nations Development Program [UNDP] (2003). Nepal: Agricultural Policy and Strategies For Poverty Alleviation and Food Security, Main Report, Kathmandu Nepal, June 2003.

Food & Agriculture Organization [FAO], (1983). Guidelines: Land Evaluation for Rain-fed Agriculture. FAO Soils Bulletin, 52, Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO], (1985). Guidelines: Land Evaluation for Irrigated Agriculture. FAO Soils Bulletin, 55, Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO], (1988). FAO-UNESCO Soil Map of the World: Revised Legend. FAO World Soil Resources Reports No 60: Rome, Italy.

Food & Agriculture Organization [FAO], (1988). Irrigation and water resources potential for Africa. FAO report AGL/M ISC/11/87. Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO], (1997). Land quality indicators and their use in sustainable agriculture and rural development. *FAO Land and Water Bulletin 5*. Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO], (2006). Global Forest Resource Assessment2005, Progrss towards sustainable forest management, FAO Forest Paper 147. Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization [FAO], (2011). Reforming forest tenure: Issues, principles and process. Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization and United Nation Environmental Progarm [FAO/UNEP] (1995). Our land our future – A new approach to land use planning and management. Food and Agriculture Organization of the United Nations, Rome, Italy.

Food & Agriculture Organization and United Nation Environmental Progarm [FAO/UNEP] (1999). The Future of our land: facing the challenge. Guidelines for integrated planning for sustainable management of land resources. Food and Agriculture Organization of the United Nations, Rome, Italy.

Foran, B., Wardle, K. (1995). Transitions in land use and the problems of planning: A case study from the mountain lands of New Zealand. *Journal of Environmental Management*, 43, 97-127.

Fukamachi, K., Oku, H., Kumagai, Y., & Shimomura, A. (2000). Changes in landscape planning and land management in arashiyama national forest in Kyoto. *Landscape and Urban Planning, 52*.

Ghanbarpour, M. R., & Hipel, K. W. (2011). Multi-criteria planning approach for ranking of land management alternatives at different spatial scales. *Research Journal of Environmental and Earth Sciences, 3*(2), 167-176.

Godschalk, D. R. (2004). Land use planning challenges: Coping with conflicts in visions of sustainable development and livable communities. *Journal of the American Planning Association*, 70 (1), 1-9.

Goldar, B., & Banerjee, N. (2004). Impact of informal regulation of pollution on water quality in rivers in India. *Journal of Environmental Management, 22,* 213-217.

Gove, N. E., Edwards, R. T., & Conquest, L. L. (2001). Effects of scale on land use and water quality relationships: A longitudinal basin-wide perspective. *Journal of American Water Resource Association, 37*(6), 1721-1734.

Gyawali, S., & Techato, K. (2011a). *The influence of agriculture land use on water quality of U-tapao river, Thailand*. Paper presented at the The 2nd International Conference on Sustainable Future for Human Security-SUSTAN 2011, Kyoto, Japan.

Gyawali, S., Techato, K., & Yuangyai, C. (2011b). *The improvement of water quality monitoring system on U-tapao river basin, Thailand*. Paper presented at the TIChE International conference, Hatyai, Songkhla, Thailand.

Gyawali, S., Techato, K., Monprpussorm, S., & Yuangyai, C. (2011c). *Integrating land use and water quality for environmental based land use planning for U-tapao river basin, Thailand*. Paper presented at the PSU=USM international conference on humanities and social science "Transforming research for sustainable community.", BP grand tower hotel, hatyai, Songkhla, Thailand.

Gyawali, S., Techato, K., & Yuangyai, C. (2012a). *Effects of industrial waste disposal on the surface water quality of U-tapao river, Thailand*. Paper presented at the International conference on environment science and engineering (ICESE, 2012), Bangkok, Thailand.

Gyawali, S., Techato, K., Titseesang, T., & Monprapussorn, S. (2012b). A study of relationship of land-use patterns and surface-water quality for sustainable development of river basin. Srinakaronin National Conference, May 29-30, 2012, Bangkok, Thailand.

Gyawali, S., Techato, K., Yuangyai, C., & Monprpussorm, S. (2012c). *The influence of urbanization on water quality of U-tapao river, Thailand*. Paper presented at the Conference on green and sustainable innovation 2012, Chiang Mai, Thailand.

Ha, H., & Stenstorm, M. K. (2003). Identfication of land use with water quality data in storm water using a neural network. *Water Research,* 37: 4222-4230.

Harbor, J. (1994). A practical method for estimating the impact of land use change on surface runoff, groundwater recharge and wetland hydrology. *Journal of American Planning Association, 60,* 91-104.

Helmer, E. H. (2004). Forest conservation and land development in Puerto Rico. *Landscope Ecology, 19,* 29-40.

Hess, A. G. R., Koch, F. H., Rubino, M. J., Eschelbach, K. A., Drew, C. A., & Favreau, J. M. (2006). Comparing the potential effectiveness of conservation planning approaches in central North Carolina, USA. *Biological Conservation*, 358-368.

Hewitt, R., & Escobar, F.(2011).The territorial dynamics of fast-growing regions: unsustainable land use change and future policy challenges in Madrid, Spain. *Applied Geography*, 31, 650-667.

Ho, H., Jie, Z., & Xiuping, X. (2003). Impacts of urbanization on land use and water quality in Xi's dong 1996 and 2003. *Agrifood Reseārach Reports, 68*, 201-215.

Hongfen, L., Guangdo, H., & Yuanjin, X. (2008). Land use/cover change auto-detection method based on fuzzy set. *Geography and Geo-information Science, 3*.

Hoyland, K., Wallace, S. W. (2001). Generating scenario trees for multistage decision problems. *Management Science*, 47 (2), 295-307.

Hu, C., & Lian, G. (2009). Scenario analysis of land use change and ecological sustainability based on GIS. Proceedings of the Eight International Conference on Machine Learning and Cybernetics, Baoding, 12-15 July, 2009.

Huang, J., Li, Q., Pontius, R. G., Klemas, V., & Hong, H. (2011). Detecting the dynamic linkage between landscape characteristics and water quality in a subtropical coastal watershed, Southeast China. *Environmental Management*.

International Union for Conservation of Nature & Natural Resources [IUCN], (1991). *Caring for the Earth : A Strategy for Sustainable Living: Gland, Switzerland, The World Conservation Union.*

International Union for Conservation of Nature & Natural Resources [IUCN], (1980). *World Conservation Strategy. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland*

Islam, K., & Sato, N. Deforestation, land conservation and illegal logging in Bangladesh: the case of the Sal (Shorea robusta) forests: *iForest*, 5:171-178.

Jain, S. K., & Singh, V. P. (2003). Water resources systems planning and management.

Jankowski, P. (1995). Integrating geographical information systems and multiple criteria decision-making methods. *International Journal of Geographical Information Science, 3*(2), 251-273.

Jankowski, P., Andrienko, N., & Andrienko, G. (2001). Map-centered exploratory approach to multiple criteria spatial decision making. *International Journal of Geographical Information Science.* 15(2), 101–127.

Jarvie, H. P., Whitton, B., & Neal, C. (1998). Nitrogen and phosphorus in east coast British rivers: Speciation sources and biological significance. *Science of the Total Environment, 210*, 210-279.

Jeon, Y. D., & Kim, Y. Y. (2000). Land reform income redistribution and agricultural production in Korea. *Economic Development and Cultural Change, 48*(2), 253-268.

Jiang, H., & Easman, J. R. (2000). Application of fuzzy measures in multi-criteria evaluation in GIS. *International Journal of Geographic Information Systems, 14*, 173-184.

Jiang, D., Dafang, Z., Xinliang,X., & Lei, Y. (2008). Integrated Evaluation of Urban Development Suitability Based on Remote Sensing and GIS Techniques – A Case Study in Jingjinji Area, China . *Sensors.* 8, 5975-5986.

Jun, T., & Zong-Guo, X. (2008). Exaimining spatially varying relationship between land use and water quality using geographically weighted regression: Model design and evaluation. *Science of the Total Environment, 40*(7), 358-378.

Kalin, L., Isik, S., Schoonover, J.E., & Lockaby, B. G. (2010). Predicting water quality in unmonitored watersheds using artifical neural networks. *Journal of Environmental Quality,* 39(4): 1429-1440.

Kannj, I., & Achi, O. (2011). Industrial effluents and their impact on water quality of receiving rivers in Nigeria. *Journal of Applied Technology in Environmental Sanitation, 1*(1), 75-86.

Kearns, F. R., Kelly, N. M., Carter, J. L., & Resh, V. H. (2005). A method of the use of landscape metrics in fresh water researach and management. *Landscape Ecology, 20*, 113-125.

Kepner, W. G, Semmens, D. J., Bassett, S. D., Mouat, D. A., & Goodrich, D. C. (2004). Scenario Analysis for the San Pedro River, Analyzing Hydrological Consequences of a Future Environment. *Journal of Environmental Monitoring and Assessment*, 94: 115-127.

Knaap, G. J., Ding, C. & Hopkins, D. (2001). Do plans matters? The effects of light rail plans on land values in station areas. *Journal of Planning Education and Research*, 21, 32-39.

Kombe, W. J. (2005). Land use dynamics in peri-urban areas and their implications on the urban growth and form: the case of Dar es Salaam, Tanzania. *Habitat International*, 29(1), 113-135.

Korashey, R. (2009). Using regression analysis to estimate water quality constituents in bahr el bagar drain. *Journal of Applied Science Research, 5*(8), 1067-1076.

Kuhn, I., Allestam, G., Engdahl, M., & Sterstrom, T. A. (1997). Biochemical fingerprinting of coliform bacterial populations-comparisons between polluted river water and factory effluents. *Water Science and Technology, 35*(11), 343-350.

Kuppusamy, M. R., & Giridhar, V. V. (2006). Factor analysis of water quality characteristics including trace metal speciation in the coastal environmental system of Chennai Ennore. *Environmental International, 32*(2), 174-179.

Lambin, E. F., Rounsevell, M. D. A., & Geist, H. J. (2000). Are agricultural land use models able to predict changes in land-use intensity? *Agriculture, Ecosystems and Environment, 82*, 321-331.

Langebein, W. B. & Iseri, K. T. (1995). General Introduction and Hydrologic Definitions. United States Government Printing Office: Washington D. C., USA.

Lee, J. Y., Yang, J. S., Kim, D. K., & Han, M. Y. (2010). Relationship between land uses and water quality in a small watershed in South Korea, Water Science & Technology, 62: 11-22.

Lee, S.W., Hwang, S J., Lee, S. B., Hwang, H. S., & Sung, H C. (2009). Landscape ecological approach to the relationships of land use patterns in watersheds to water quality characteristics. *Landscape and Urban Planning, 92*, 80–89.

Lepers, E., Lambin, E.F., Janetos, A.C., Defries, R., Achard, F., Ramankutty, N., & Scholes, R.J. (2005). A synthesis of information on rapid land-cover change for the period 1981-2000. *Bio-science,* 55(2), 115-124.

Li, S., Gu, S., Liu, W., Han, H., & Zhang, Q. (2008). Water quality in relation to land use and land cover in the upper Han river basin, China. *Catena, 75*, 216-222.

Li, S., Gu, S., Tan, X., & Zhang, Q. (2009). Water quality in the upper Han river basin, Cina: The impacts of land use/land cover in riparian buffer zone. *Journal of Hazardous Materials, 165*, 317-324.

Lo, C. P., & Yeng, A. K. W. (2002). *Concepts and Techniques of Geographic Information Systems*. New Delhi, India.

Mahvi, A. H., Nouri, J., Babaei, A. A. and Nabizadeh, R. (2005). Agricultural activities impact on groundwater nitrate pollution. *International Journal of Environmental Science and Technology, 2*(1), 41-47.

Malcewski, J. (2006), GIS-based multicriteria decision analysis: A survey of the literature. *Int. J. Geog. Inf. Syst.* 20, 703-726.

Malczewski, J. (1996). A GIS-based Approach to Multiple Criteria Group Decision Making. International Journal of Geographical Information System, *10*(8), 955-971.

Malczewski, J. (2004). GIS-based approach to multiple criteria group decision-making. *International Journal of Geographic Information Science, 10*, 955-971.

Mander, U., Kull, A., Tamm, V., Kuusemets, V., & Karjus, R. (1998). Impact of climatic fluctuations and land use change on runoff and nutrient lossess in rural landscape. *Landscape and Urban Planning, 41*, 229-238.

Master Plan for Songkhla Lake Basin Development [MPSLBD]. (2003). *Executive Summary* (ISBN 974-644-626-6). Hat Yai: Thailand. Neo Point Press.

Meyer, J. L., Paul, M. J., & Taulbee, W. K. (2005). Stream ecosystem function in urbanizing landscapes. *Journal of the North American Benthological Society, 24*, 602-612.

meynendonckx, J., Heuvelmans, G., Muys, B., & Feyen, J. (2006). Effects of watershed and riparian zone characteristics on nutrient concentrations in the river scheldt basin. *Hydrology and Earth System Sciences, 10,* 913-922.

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

Mitchell, B. (2005). Integrated Water resource management, institutional arrangements, and land use planning. *Environmental and Planning A*, 37: 1335-1352.

Mohren, G.M.J.(2003). Large-scale scenario analysis in forest ecology and forest management. *Forest Policy and Economics,* 5, 103–110.

Moscrip, A. L., & Montgomery, D. R. (1997). urbanization, flood, frequency, and salmon, abundance in Puget Lowland Streams. *Journal of the American Water Resources Association, 33*(6), 1289-1297.

Mustafa, A. A., Singh, M., Sahoo, R. N., Ahded, N., Khanna, M., Sarangi, A., & Mishra, A. K. (2011). Land suitability analysis for different crops: A multi criteria decision making approach using remote sensing and GIS. *Researchers, 3*(12), 61-84.

Najafpour, S., Alkarkhi, A. F. M., Kadir, M. O. A., & Najafpour, G. D. (2008). Evaluation of spatial and temporal variation in river water quality. *International Journal of Environmental Research, 2*(4), 349-358.

Nakane, K., & haidary, A. (2010). Sensitivity analysis of stream water quality and land cover linkage models using monte carlo method. *International Journal of Environmental Research, 4*(1), 121-130.

Nambia Institute for Democracy [NID]. (2000). *Understanding of Land Use Planning and it's Relevance in Namibia.* Ministry of Lands and Resettlement: Nambia.

Ngoye, E., & Machiwa, J. F. (2004). The influence of land-use patterns in the Ruvu river watershed on water quality in the river basin. *Physics, Chemistry of the Earth*, *29*, 1161-1166.

Norton, R. (2005). More and better local planning: State-mandated local planning in coastal North Carolina. *Journal of the American Planning Association,* 71 (1), 55-72.

O'Driscall, M., Clinton, S., Jefferson, A., Manda, A., & McMillan, S. (2010). Urbanization effects on watershed hydrology and in-stream process on the southern United States. *Water, 2,* 605-648.

Ojutiku, R. O., & Kolo, J. (2011). Temporal and spatial variation of physcio-chemical parameters of rivers chanchaga, Niger State, Nigeria. *Journal of Applied Biosciences, 47,* 3242-3255.

Osibanjio, O., Daso, O., & Ghadebo, A. M. (2011). The impact of industries on surface water quality of river ona and river aloro in Oluyoke Industrial Estate, Ibadan, Nigeria. *African Journal of Biotechnology, 10*(4), 696-702.

Paiboonsak, S., Chanket U., Yommaraka B., & Mongkolsawat, C. (2004). Land suitability evaluation for sugarcane, GIS application. In proceeding 25th AC2004 on November 22-26, 2004 at Chiang Mai. Thailand.

Park S., Jeon, S., Kim, S., & Choi, C. (2011). Prediction and comparison of urban growth by land suitability index mapping using GIS and RS in South Korea. *Landscape and Urban Planning. 99, 104–114.*

Pejman, A. H., Bidhendi, G. R., Karbassi, A. R., Mehrdadi, N., & Bidendi, M. E. (2009). Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques. *International Journal of Environment Science and Technology, 63*(3), 467-476.

Pikounis, M., Varanou, E., Baltas, E., Dassaklis, A., & Mimikou, M. (2003). Application of the Swat Model in the Pinios River Basin under Different Land-Use Scenarios. *Global Nest: the International Journal*, 5(2), 71-79.

Pompeu, P., & Alves, C. (2005). The effects of urbanization on biodiversity and water quality. *American Fisheries Society Symposium, 47*, 11-12.

Pornipaatepong, K., Kiripat, S., Treewanchai, S., & Chongwilaikasaem, S. (2010). *Pollution control and sustainable fisheries management in southern songkhla lake Thailand*. Paper presented at the 4th World Congress of Environmental and Resources Economics, Mentreal, Canada.

Prakash, T. N. (2003). *Land suitability analysis for agricultual crosp: A fuzzy multicriteria decision making approach.* MSc, ITC, Netherlands.

Raghunath, M. (2006). *Application of remote sensing and GIS in urban land suitability modeling at parcel level using multi-criteria decision analysis,* Master, Andhra University, Visakhapatnam, India.

Rahim, S.M., Hasnain, S., & Shamsi, R.A. (2010). Land suitability classification of choice of trees species in District Rahim Yar Khan, Punjab, Pakistan. *African Journal of Agricultural Research. 5(23), 3219-3229.*

Ranst, E. V., Tang, H., Groenemans, R., & Sinthurahat, S. (1996). Application of fuzzy logic to land suitability for rubber production in peninsular, Thailand. *Geoderma, 70*, 1-19.

Ren, E. V., Zhong, Y., Meligrana, J., Anderson, B., Watt, W. C., Chan, J., & Leng, H. L. (2003). Urbanization land use and water quality in Shanghai 1947-1996. *Environment International, 29*, 249-258.

Ribbe, L., Gaese, H., Salgado, E., Roehrig, J., & Kretschmer, N. (2009). *Assessing the impact of agriculture on water quality: A case study from central Chile.* University of Applied Sciences Cologne.

Richards, C. & Host, G. (1994). Examining land-use influences on stream habitats and macroinvertebrates:a GIS approach. *Water Resources Bulletin*, 3, 729–738.

Rothenberger, M. B., Burkholder, J. M., & Brownie, C. (2009). Long term effects of changing land use practices on surface water quality in a coastal river and lagoonal estuary. *Environmental Management, 44*, 505-523.

Rothwell, J.J., Dise, N.B., Taylor, K.G., Alott, T.E.H., Scholefield, P., Davies, H., & Neal, C. (2010). Predicting river water quality across North West England using catchment characteristics, *Journal of Hydrology*, 395, 153–162.

Saaty, T. L. (1980). *The analytic hierarachy process*. New York: McGraw Hill International.

Saaty, T. L. & Vargas, L.G.(1988). Decision Making in Economic, Political, Social, and Technological Environment with the Analytic Hierarchy Process. RWS Publications, Pittsburgh, USA.

Saaty, T. L (2000). Fundamentals of decision making and priority theory with the analytic hierarchy process: RWS Publications, Pittsburgh., USA.

Sachs, I. (1992). Transition strategies for the 21 st century. *Nature and Resources, 28*, 4-17.

Samat, N. (2006). *Applications of geographic information systems in urban land use planning in Malaysia*. Paper presented at the The 4th Taipei International Conference on Digital Earth, Taiwan.

Sandovala, C., Flanders, D., & Kozak, R. A. (2010). Participatory landscape planning and sustainable community development: Methodological observations from a case study in rural Mexico. *Landscape and Urban Planning, 94,* 63-70.

Saroinsong F., Harashina , K., Arifin, H., Gandasasmita, K., & Sakamoto, K. (2007). Practical application of a land resources information system for agricultural landscape planning. *Landscape and Urban Planning, 79,* 38–52.

Schueler, T.R (1994). The importance of imperviousness. *Watershed Protection Techniques, 1 (3),* 100–111.

Shrestha, G., & Kazama, F. (2007). Assessment of surface water quality using multivariate statistical technique: A case study of the Fuji River Basin, Japan. *Environmental Modelling & Software, 22*, 464-475.

Shrestha, G., Sadohara, S., Masunaga, S., Kondo, H., Yoshida, S., & Sato, Y. (2011). River water quality analysis of hadano basin and its relationship with nonpoint sources of pollution. *Journal of Water and Environment Technology, 9*(2), 141-168.

Sieber, R. (2006). Public Participation Geographic Information Systems: A Literature Review and Framework. *Annals of the Association of American Geographers, 96(3),* 491–507.

Singh, K. P., Malik, A., Mohan, D., & Sinha, S. (2004). Multivariate statistical techniques for the evaluation of spatial and temporal variations in water quality of Gomati river (India): A case study. *Water Reseaarch, 38,* 3980-3992.

Sirtnawin, W., & Sompongchaiyakul, P. (2005). Nondetrital and total metal distribution in core sediments from the U-tapao canal, Songkhla, Thailand. *Marine Chemistry, 94,* 5-16.

Sliva, L., & Williams, D. D. (2001). Buffer zone versus whole catchment approaches to studying land use impact on river water quality. *Water Research, 35*(14), 3426-3472.

Son, N. T., & Shrestha, R. P. (2008). GIS-assisted land evaluation for agricultural development in 204 odeli delta, southern Vietnam. *Journal of Sustainable Development in Africa, 10*(2).

Store, R., & Kangas, J. (2001). Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability 205 odeling. *Landscape and Urban Planning*, *55*(2), 79-93.

Tanriverdi, C., Alp, A., Demirkiran, A. R. and Ucjarde, F. (2010). Assessment of surface water quality of the Ceyhan River basin, Turkey. *Environmental Monitoring and Assessment*, 167, 175-184.

Thapa, R. B., & Murayama, Y. (2007). Land evaluation for peri-urban agriculture using analytical heirarchical process and geographic information system techniques: A case study of Hanoi. *Land Use Policy, 25*, 225-239.

Thebald, D. M. & Hobbs, N. T.(2002). A framework for evaluating land use alternatives: protecting biodiversity on private land. *Conservation Ecology*, 6(1), 5- 46.

Thiparpa, Y. (2007). Water quality monitoring and water quality situation in Thailand: Ministry of Science, Technology and Energy, Thailand.

Titenwong, K., Dasananda, S., Navanugraha C. (2009). Integration of land evaluation and the analytical hierarchical process method for energy crops in Kanchanaburi, Thailand. *ScienceAsia, 35,*170-177

Tong, S. T. Y. (1990). The hydrologic effects of urban land use: A case study of the little Miami river basin. *Landscape and Urban Planning, 19*, 99-105.

Tong, S. T. Y., & Chen, W. (2002). Modeling the relationship between land use and surface water quality *Journal of Environmental Management, 66*, 377-393.

Traichaiyaporn, S. & Chitmanat, C. (2008). Water Quality Monitoirng in Upper Ping River Thailand. *Journal of Agriculture & Social Sciences*. (4), 31-34.

Tu, J. (2011). Spatially varying relationships between land use and water quality across an urbanization gradient explored by geographically weighted regression. *Applied Geography, 31*, 376-392.

Tu, J., & Xia, Z. G. (2006). Assessing the impact of land use changes on water quality across multiple spatial scales in easterm Massachusetts. *Middle States Geographer, 39*, 34-42.

Tu, J., & Xia, Z. G. (2010). Examining spatially varying relationship between landuse and water quality using geographically weighted regression I: Model design and evaluation *Science of the Total Environment, 407*, 358-378.

United Nations Environment Programme- World Conservation Monitoring Centre [UNEP-WCMC] (2009). *Annual Report 2009*: UN

United States Agency for International Development [USAID] (1988). Committee for Agriculture Sustainable Development for Developing Countries, Washington, D.C.

United States Environment Protection Agency [US-EPA]. (1994). *EPA- First Year Progress Report*: United States Environmental Protection Agency.

Uriarte, M., Yackulic, C.B., Lim, Y., Arce-Nazario, J. A. (2011). Influence of land use on water quality in a tropical landscape: a multi-scale analysis. *Landscape Ecology*, 26, 1151–1164.

Wali, K. P., & Hatano, R. (2002). Evaluating impact of land use and N budgets on stream water quality in Hokkaido, Japan. *Nutrient Cycling in Agroecosystems, 63*, 175-184.

Wang, L., Lyons, J., & Kanehl, P. (2011). Impact of urbanization on stream habitat and fish across multiple spatial scales. *Environmental Management, 28*(2), 255-266.

Wang, X. (2001). Integrating water quality management and land-use planning in a watershed context. *Journal of Environmental Management, 61*, 25-36.

Wit, D. P., & Lindsay, J. (2000). From vision to implementation: Putting Ghana's national land policy into action, FAO Project TCP/GHA/6751-0065. Accra, Ghana.

Woli, K. P., Hayakawa, A., Nagumo, T., Imai, H., Ishiwata, T., & Hatano, R. (2008). Assessing the impact of phosphorous cycling on river water P concentration in Hokkaido. *Soil Science and Plant Nutrition, 54,* 310-317.

World Bank [WB] (2006). Sustainable Land Management : Challenges, Opportunités and Trade-offs ; the World Bank, Washington DC.

World Commission and Environment Development [WCED] (1987). Our Common Future: Oxford University Press, UK.

World Health Organization [WHO]. (1993) .*Guidelines for Drinking-Water Quality, Volume 1, Recommendations.* 2nd edition, World Health Organization, Geneva.

Xian, G. Crane, M., & Su, J. (2007). An analysis of urban development and its environmental impact on the Tampa Bay Watershed. *Journal of Environmental Management, 25,* 965-976.

Yang, L., Xian, G., Klaver, J. M., & Deal, B. (2003). Urban land-cover change detection through sub-pixel imperviousness maping using remotely sensed data. *Photogrammetric Engineering & Remote Sensing, 77*, 29-38.

Yang, X., & Jin, W. (2010). GIS-based spatial regression and prediction of water quality in river networks: A case study in Iowa. *Journal of Environmental Management, 91*, 1943-1951.

Yin, Z. Y., Walcott, S., Kaplan, B., Cao, J., Lin, W., & Chen, M. (2005). An analysis of the relationship between spatial patterns of water quality and urban development in Shanghai, China. *Computer, Environment and Urban Systems, 29*, 197-221.

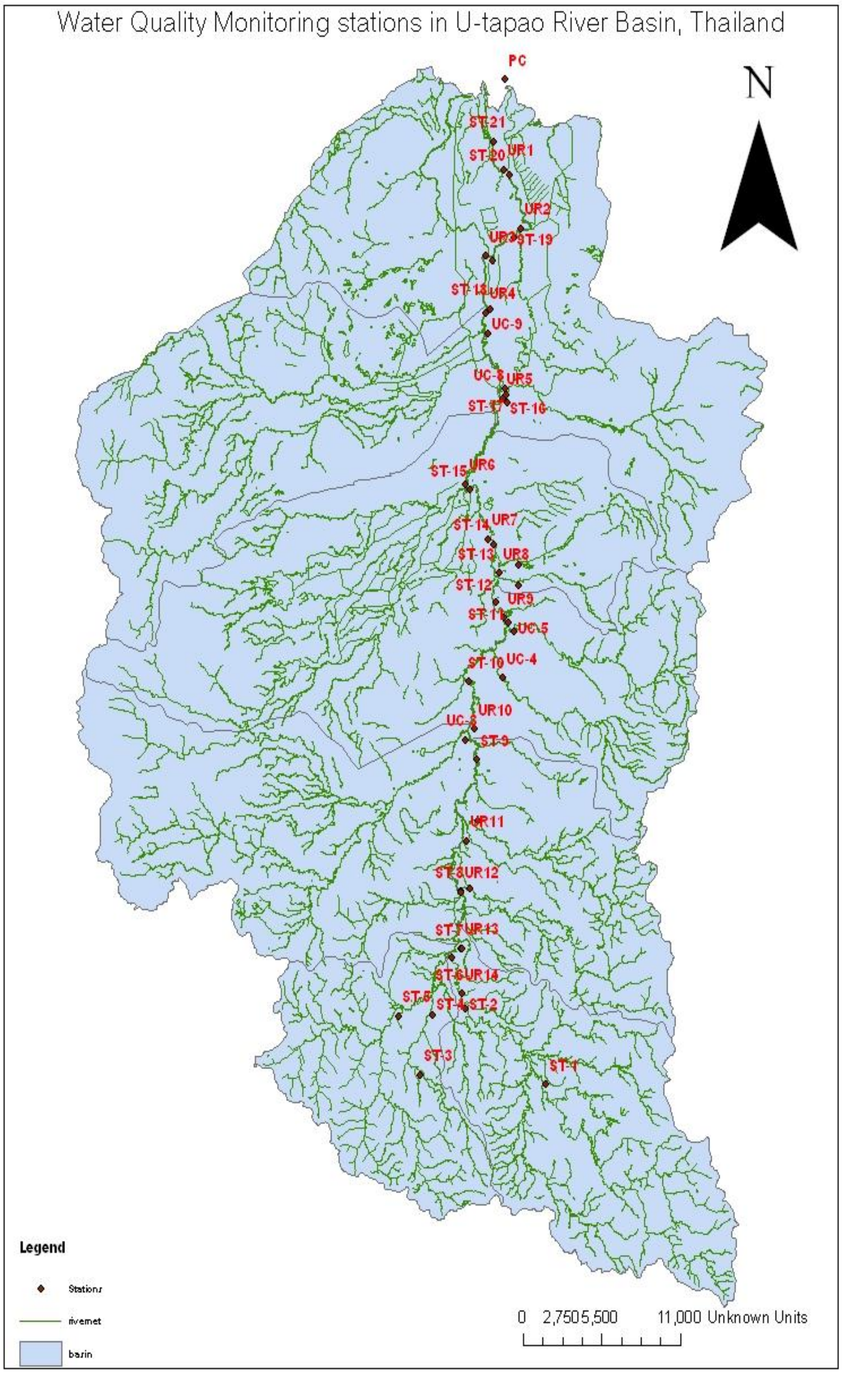
Yu, S., Shang, J., Zhao, J., & Guo, H. (2003). Factor analysis and dynamics of water quality of the Songhua River Northeast China. *Water Air Soil Pollution*, 144, 159-169.

Zampella, R. A., Procopion, N. A., Lathrop, R. G., & Dow, C. L. (2007). Relationship of land-use/land-cover pattern and surface-water quality in the Mullica river basin. *Journal of the American Water Resources Association, 4*(3), 594-604.

APPENDICES

APPENDIX A

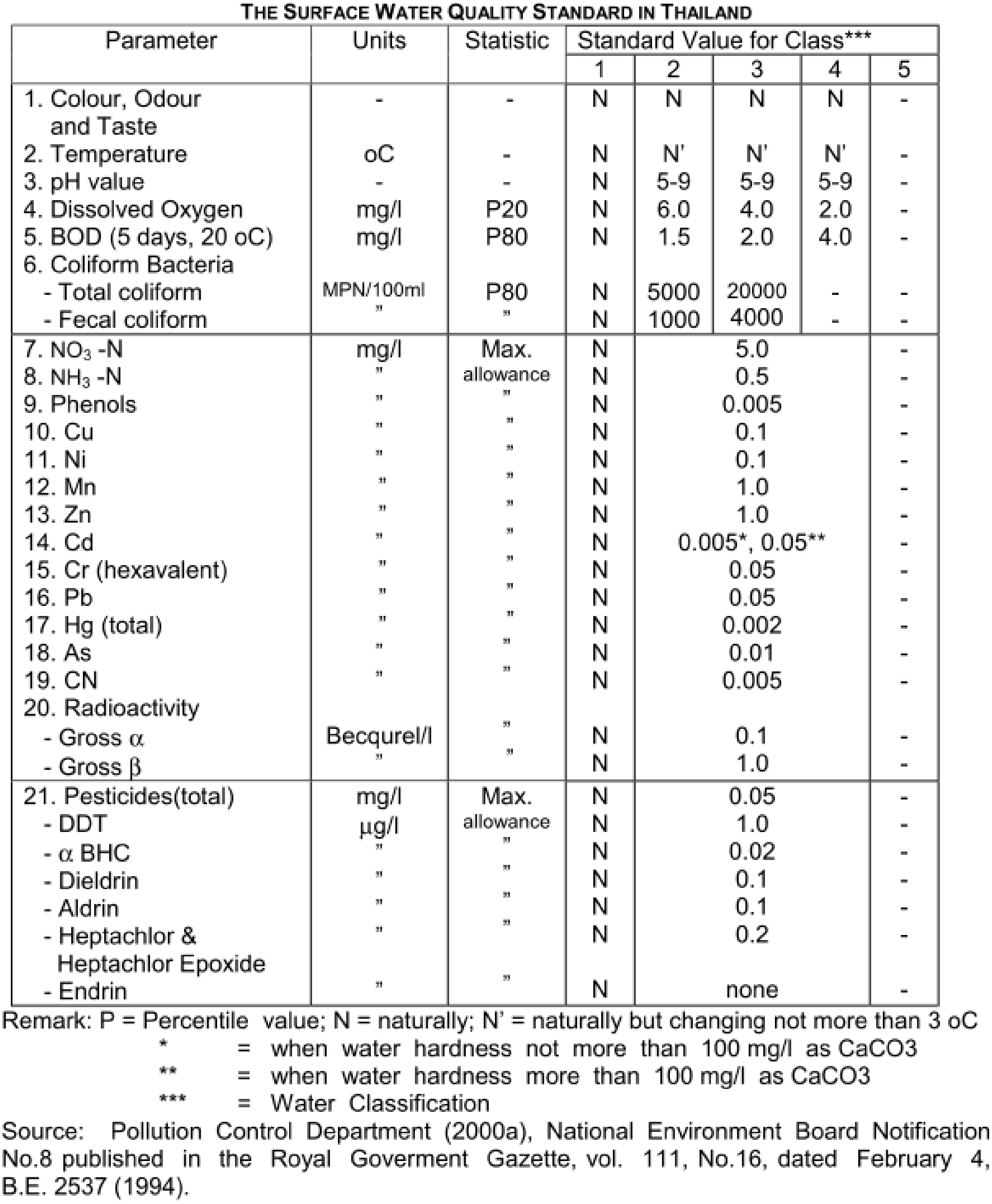
Water Quality Monitoring Stations of U-tapao River Basin, Thailand



ST-1	Sapan langwat huayku
ST-2	Office of Water Work, Sa
ST-3	Mitr Sampan Community
ST-4	Sanepong School Bridge
ST-5	Ban Nam Hua Bridge
ST-6	Safe Skin Industry
ST-7	Ban Huathanon Bridge
ST-8	Ban Takian Pao Bridge
ST-9	Ban Tha Pho Ok Bridge
ST-10	Muang Kong Temple Bri
ST-11	Ban Prao Bridge
ST-12	Siam Fibre Board Cooper
ST-13	Ban Klong Pom Bridge
ST-14	Public Works Bridge, Kl
ST-15	Bangsala Temple Bridge
ST-16	Hatyai University Bridge
ST-17	U-tapao Canal Water Gat
ST-18	Ta Sae Temple Bridge
ST-19	Narong Nok Temple Brid
ST-20	Wat Kutao Bridge
ST-21	Songkhla Laguna Bridge
UR-1	Safan ban kutao
UR-2	Safan ban Narungnok
UR-3	Safan Ban Maeton
UR-4	Safan Rotfai
UR-5	Safan Than Luwang Mila
UR-6	Safan ban Bangsala
UR-7	Safan Krom Yothathikan
UR-8	Safan Ban Tunglung
UR-9	Safan Than Luwangmilak
UC-1	Mid Songkla Bridge
UC-2	Phankla Canael
UC-3	Mosque
UC-4	Prata Cannel
UC-5	Tom Cannel
UC-6	Hinlakephi Cannel
UC-7	Pom Cannel
UC-8	CrongWa Cannel
UC-9	Crongwat Cannel
UC-10	Crongban Cannel

APPENDIX-B

The Surface water quality standard in Thailand



THE SURFACE WATER QUALITY STANDARD IN THAILAND

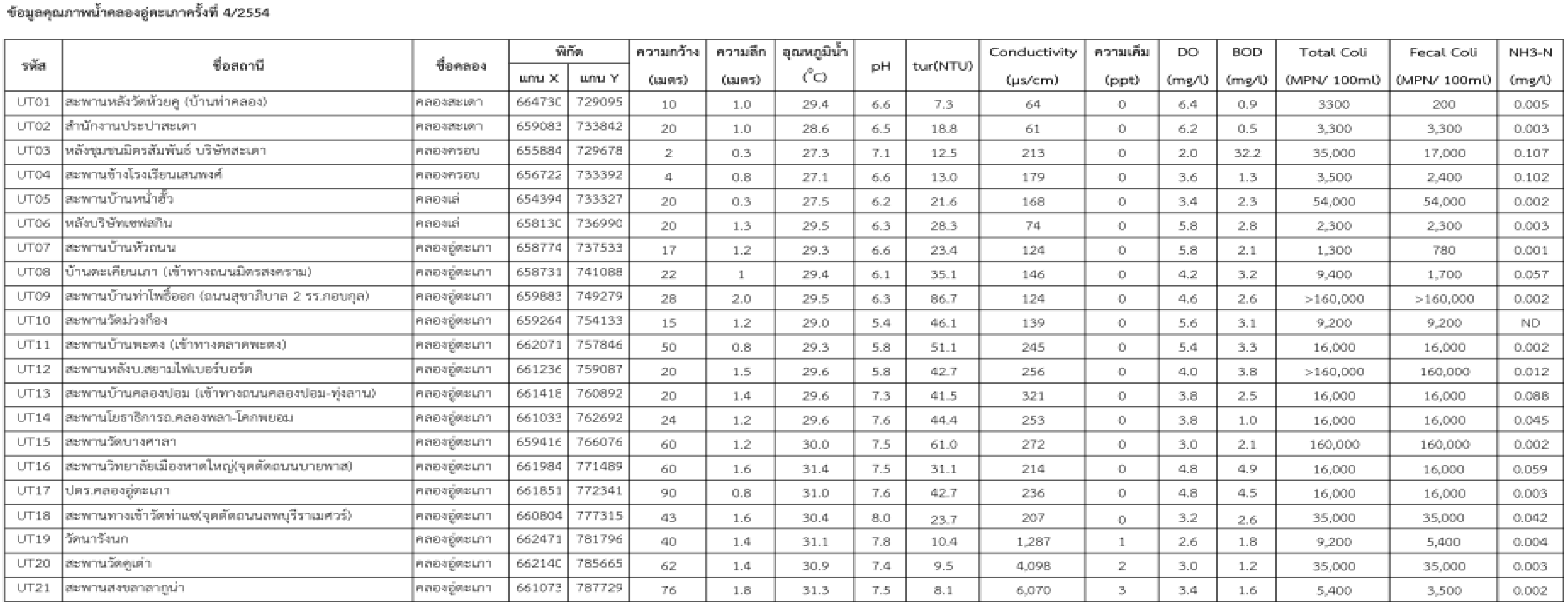
Parameter	Units	Statistic	Standard Value for Class***				
			1	2	3	4	5
1. Colour, Odour and Taste	-	-	N	N	N	N	-
2. Temperature	oC	-	N	N'	N'	N'	-
3. pH value	-	-	N	5-9	5-9	5-9	-
4. Dissolved Oxygen	mg/l	P20	N	6.0	4.0	2.0	-
5. BOD (5 days, 20 oC)	mg/l	P80	N	1.5	2.0	4.0	-
6. Coliform Bacteria							
- Total coliform	MPN/100ml	P80	N	5000	20000	-	-
- Fecal coliform	"	"	N	1000	4000	-	-
7. NO_3 -N	mg/l	Max.	N	5.0			-
8. NH_3 -N	"	allowance	N	0.5			-
9. Phenols	"	"	N	0.005			-
10. Cu	"	"	N	0.1			-
11. Ni	"	"	N	0.1			-
12. Mn	"	"	N	1.0			-
13. Zn	"	"	N	1.0			-
14. Cd	"	"	N	0.005*, 0.05**			-
15. Cr (hexavalent)	"	"	N	0.05			-
16. Pb	"	"	N	0.05			-
17. Hg (total)	"	"	N	0.002			-
18. As	"	"	N	0.01			-
19. CN	"	"	N	0.005			-
20. Radioactivity							
- Gross α	Becqurel/l	"	N	0.1			-
- Gross β	"	"	N	1.0			-
21. Pesticides(total)	mg/l	Max.	N	0.05			-
- DDT	µg/l	allowance	N	1.0			-
- α BHC	"	"	N	0.02			-
- Dieldrin	"	"	N	0.1			-
- Aldrin	"	"	N	0.1			-
- Heptachlor & Heptachlor Epoxide	"	"	N	0.2			-
- Endrin	"	"	N	none			-

Remark: P = Percentile value; N = naturally; N' = naturally but changing not more than 3 oC
* = when water hardness not more than 100 mg/l as CaCO3
** = when water hardness more than 100 mg/l as CaCO3
*** = Water Classification

Source: Pollution Control Department (2000a), National Environment Board Notification No.8 published in the Royal Goverment Gazette, vol. 111, No.16, dated February 4, B.E. 2537 (1994).

APPENDIX C

Water quality data of different monitoring stations of U-tapao River Basin



ข้อมูลคุณภาพน้ำคลองอู่ตะเภาครั้งที่ 4/2554

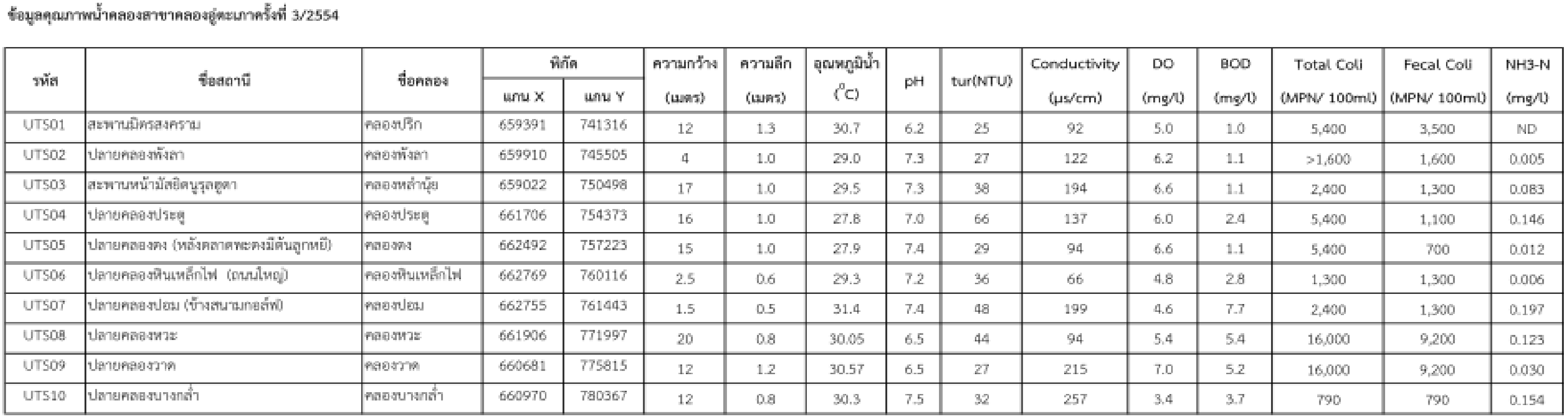
รหัส	ชื่อสถานี	ชื่อคลอง	พิกัด		ความกว้าง (เมตร)	ความลึก (เมตร)	อุณหภูมิน้ำ (°C)	pH	tur(NTU)	Conductivity (µs/cm)	ความเค็ม (ppt)	DO (mg/l)	BOD (mg/l)	Total Coli (MPN/ 100ml)	Fecal Coli (MPN/ 100ml)	NH3-N (mg/l)
			แกน X	แกน Y												
UT01	สะพานหลังวัดห้วยคู (บ้านท่าคลอง)	คลองสะเดา	664730	729095	10	1.0	29.4	6.6	7.3	64	0	6.4	0.9	3300	200	0.005
UT02	สำนักงานประปาสะเดา	คลองสะเดา	659083	733842	20	1.0	28.6	6.5	18.8	61	0	6.2	0.5	3,300	3,300	0.003
UT03	หลังชุมชนมิตรสัมพันธ์ บริษัทสะเดา	คลองครอบ	655884	729678	2	0.3	27.3	7.1	12.5	213	0	2.0	32.2	35,000	17,000	0.107
UT04	สะพานข้างโรงเรียนเสนพงศ์	คลองครอบ	656722	733392	4	0.8	27.1	6.6	13.0	179	0	3.6	1.3	3,500	2,400	0.102
UT05	สะพานบ้านหน้าฮั้ว	คลองแล่	654394	733327	20	0.3	27.5	6.2	21.6	168	0	3.4	2.3	54,000	54,000	0.002
UT06	หลังบริษัทเซฟสกิน	คลองแล่	658130	736990	20	1.3	29.5	6.3	28.3	74	0	5.8	2.8	2,300	2,300	0.003
UT07	สะพานบ้านหัวถนน	คลองอู่ตะเภา	658774	737533	17	1.2	29.3	6.6	23.4	124	0	5.8	2.1	1,300	780	0.001
UT08	บ้านตะเคียนเภา (เข้าทางถนนมิตรสงคราม)	คลองอู่ตะเภา	658731	741088	22	1	29.4	6.1	35.1	146	0	4.2	3.2	9,400	1,700	0.057
UT09	สะพานบ้านท่าโพธิ์ออก (ถนนสุขาภิบาล 2 รร.กอบกุล)	คลองอู่ตะเภา	659883	749279	28	2.0	29.5	6.3	86.7	124	0	4.6	2.6	>160,000	>160,000	0.002
UT10	สะพานวัดม่วงก็อง	คลองอู่ตะเภา	659264	754133	15	1.2	29.0	5.4	46.1	139	0	5.6	3.1	9,200	9,200	ND
UT11	สะพานบ้านพะตง (เข้าทางตลาดพะตง)	คลองอู่ตะเภา	662071	757846	50	0.8	29.3	5.8	51.1	245	0	5.4	3.3	16,000	16,000	0.002
UT12	สะพานหลังบ.สยามไฟเบอร์บอร์ด	คลองอู่ตะเภา	661236	759087	20	1.5	29.6	5.8	42.7	256	0	4.0	3.8	>160,000	160,000	0.012
UT13	สะพานบ้านคลองปอม (เข้าทางถนนคลองปอม-ทุ่งลาน)	คลองอู่ตะเภา	661418	760892	20	1.4	29.6	7.3	41.5	321	0	3.8	2.5	16,000	16,000	0.088
UT14	สะพานโยธาธิการอ.คลองพลา-โคกพยอม	คลองอู่ตะเภา	661033	762692	24	1.2	29.6	7.6	44.4	253	0	3.8	1.0	16,000	16,000	0.045
UT15	สะพานวัดบางศาลา	คลองอู่ตะเภา	659416	766076	60	1.2	30.0	7.5	61.0	272	0	3.0	2.1	160,000	160,000	0.002
UT16	สะพานวิทยาลัยเมืองหาดใหญ่(จุดตัดถนนบายพาส)	คลองอู่ตะเภา	661984	771489	60	1.6	31.4	7.5	31.1	214	0	4.8	4.9	16,000	16,000	0.059
UT17	ปตร.คลองอู่ตะเภา	คลองอู่ตะเภา	661851	772341	90	0.8	31.0	7.6	42.7	236	0	4.8	4.5	16,000	16,000	0.003
UT18	สะพานทางเข้าวัดท่าแซ(จุดตัดถนนลพบุรีราเมศวร์)	คลองอู่ตะเภา	660804	777315	43	1.6	30.4	8.0	23.7	207	0	3.2	2.6	35,000	35,000	0.042
UT19	วัดนารังนก	คลองอู่ตะเภา	662471	781796	40	1.4	31.1	7.8	10.4	1,287	1	2.6	1.8	9,200	5,400	0.004
UT20	สะพานวัดคูเต่า	คลองอู่ตะเภา	662140	785665	62	1.4	30.9	7.4	9.5	4,098	2	3.0	1.2	35,000	35,000	0.003
UT21	สะพานสงขลาลากูน่า	คลองอู่ตะเภา	661073	787729	76	1.8	31.3	7.5	8.1	6,070	3	3.4	1.6	5,400	3,500	0.002

ข้อมูลคุณภาพน้ำคลองสาขาคลองอู่ตะเภาครั้งที่ 4/2554

รหัส	ชื่อสถานี	ชื่อคลอง	พิกัด		ความกว้าง	ความลึก	อุณหภูมิน้ำ	pH	tur(NTU)	Conductivity	ความเค็ม	DO	BOD	Total Coli	Fecal Coli	NH3-N
			แกน X	แกน Y	(เมตร)	(เมตร)	($^{\circ}$C)			(µs/cm)	(ppt)	(mg/l)	(mg/l)	(MPN/ 100ml)	(MPN/ 100ml)	(mg/l)
UTS01	สะพานมิตรสงคราม	คลองปริก	659391	741316	12	1.0	29.5	6.1	22	135	0	2.4	3.4	>160,000	>160,000	0.001
UTS02	ปลายคลองพังลา	คลองพังลา	659910	745505	4	0.5	28.2	6.2	84	127	0	6.2	1.7	7,900	7,900	0.001
UTS03	สะพานหน้ามัสยิดนูรุลฮูดา	คลองหลำนุ้ย	659022	750498	17	0.6	27.6	6.8	128	137	0	6.0	1.9	7,900	7,900	0.002
UTS04	ปลายคลองประตู	คลองประตู	661706	754373	16	0.6	27.0	4.6	7	291	0	7.2	2.7	9,200	9,200	0.010
UTS05	ปลายคลองตง (หลังตลาดพะตงมีต้นลูกหยี)	คลองตง	662492	757223	15	0.6	28.0	5.7	51	96	0	6.2	2.8	9,200	9,200	0.002
UTS06	ปลายคลองหินเหล็กไฟ (ถนนใหญ่)	คลองหินเหล็กไฟ	662769	760116	2.5	0.5	26.9	7.5	25	66	0	5.0	4.0	5,400	5,400	ND
UTS07	ปลายคลองปอม (ข้างสนามกอล์ฟ)	คลองปอม	662755	761443	1.5	0.5	29.3	8.7	14	101	0	4.8	3.3	16,000	16,000	ND
UTS08	ปลายคลองหวะ	คลองหวะ	661906	771997	20	1.0	30.4	7.5	47	163	0	5.8	6.1	>160,000	>160,000	0.011
UTS09	ปลายคลองวาด	คลองวาด	660681	775815	12	1.3	29.8	7.6	25	323	0	3.0	2.7	35,000	35,000	0.002
UTS10	ปลายคลองบางกล่ำ	คลองบางกล่ำ	660970	780367	12	1.2	29.9	7.5	103	231	0	2.8	2.2	13,000	7,900	0.002

ข้อมูลคุณภาพน้ำคลองอู่ตะเภาครั้งที่ 3/2554

รหัส	ชื่อสถานี	ชื่อคลอง	พิกัด		ความกว้าง (เมตร)	ความลึก (เมตร)	อุณหภูมิน้ำ (°C)	pH	tur(NTU)	Conductivity (µs/cm)	DO (mg/l)	BOD (mg/l)	Total Coli (MPN/ 100ml)	Fecal Coli (MPN/ 100ml)	NH3-N (mg/l)
			แกน X	แกน Y											
UT01	สะพานหลังวัดห้วยคู (บ้านท่าคลอง)	คลองสะเดา	664730	729095	10	0.8	29.0	6.3	4.3	44	6.2	0.4	230	130	0.066
UT02	สำนักงานประปาสะเดา	คลองสะเดา	659083	733842	20	0.8	29.0	6.6	10.6	60	6.0	0.6	1,700	790	0.021
UT03	หลังชุมชนมิตรสัมพันธ์ บริษัทสะเดา	คลองครอบ	655884	729678	2	0.4	28.8	6.3	4.9	249	5.6	1.7	5,400	5,400	0.062
UT04	สะพานข้างโรงเรียนแสนพงศ์	คลองครอบ	656722	733392	4	0.4	28.6	6.2	21.9	119	6.0	1.5	5,400	2,400	0.029
UT05	สะพานบ้านหน่ำฮั้ว	คลองแม่	654394	733327	20	0.8	28.8	6.2	55.2	144	5.0	2.6	9,200	9,200	0.114
UT06	หลังบริษัทเซฟสกิน	คลองแม่	658130	736990	20	0.8	30.0	6.2	43.3	150	5.0	2.1	5,400	5,400	0.176
UT07	สะพานบ้านหัวถนน	คลองอู่ตะเภา	658774	737533	17	1.6	29.5	6.2	27.1	122	5.0	1.8	9,200	2,800	0.059
UT08	บ้านตะเคียนเภา (เข้าทางถนนมิตรสงคราม)	คลองอู่ตะเภา	658731	741088	22	1.5	29.9	6.2	40.8	122	4.4	1.8	3,500	3,500	0.054
UT09	สะพานบ้านท่าโพธิ์ออก (ถนนสุขาภิบาล 2 รร.กอบกุล)	คลองอู่ตะเภา	659883	749279	28	1.2	30.2	7.3	43.4	123	5.2	1.7	790	490	ND
UT10	สะพานวัดม่วงก็อง	คลองอู่ตะเภา	659264	754133	15	1.0	31.0	7.4	60.6	168	5.0	2.5	3,500	3,500	0.066
UT11	สะพานบ้านพะตง (เข้าทางตลาดพะตง)	คลองอู่ตะเภา	662071	757846	50	1.2	28.7	7.6	62.0	174	5.0	2.6	9,200	1,700	0.157
UT12	สะพานหลังบ.สยามไฟเบอร์บอร์ด	คลองอู่ตะเภา	661236	759087	20	1.6	29.8	6.9	63.9	82	5.8	4.9	2,400	2,400	0.111
UT13	สะพานบ้านคลองปอม (เข้าทางถนนคลองปอม-ทุ่งลาน)	คลองอู่ตะเภา	661418	760892	20	1.4	29.7	6.8	54.8	164	4.8	3.7	9,200	9,200	0.035
UT14	สะพานโยธาธิการต.คลองหลา-โคกพยอม	คลองอู่ตะเภา	661033	762692	24	1.0	30.2	6.8	56.6	144	4.6	3.7	9,200	9,200	0.042
UT15	สะพานวัดบางศาลา	คลองอู่ตะเภา	659416	766076	60	1.4	30.1	6.9	48.2	146	4.2	3.5	9,200	9,200	0.175
UT16	สะพานวิทยาลัยเมืองหาดใหญ่(จุดตัดถนนบายพาส)	คลองอู่ตะเภา	661984	771489	60	1.6	30.7	6.7	61.8	120	4.2	3.7	2,200	1,400	ND
UT17	ปตร.คลองอู่ตะเภา	คลองอู่ตะเภา	661851	772341	90	3.5	30.3	6.4	59.5	106	4.8	4.2	9,200	5,400	0.008
UT18	สะพานทางเข้าวัดท่าแซ(จุดตัดถนนลพบุรีราเมศวร์)	คลองอู่ตะเภา	660804	777315	43	1.5	29.5	7.9	90.2	129	3.2	3.0	>16,000	>16,000	0.130
UT19	วัดนารังนก	คลองอู่ตะเภา	662471	781796	40	1.5	30.1	7.4	61.4	153	2.0	3.9	>16,000	>16,000	0.397
UT20	สะพานวัดคูเต่า	คลองอู่ตะเภา	662140	785665	62	1.8	29.8	7.1	47.0	165	1.6	5.8	>16,000	>16,000	0.117
UT21	สะพานสงขลาอาภูน่า	คลองอู่ตะเภา	661073	787729	76	2.0	30.4	7.2	47.4	198	1.4	6.6	>16,000	>16,000	0.096

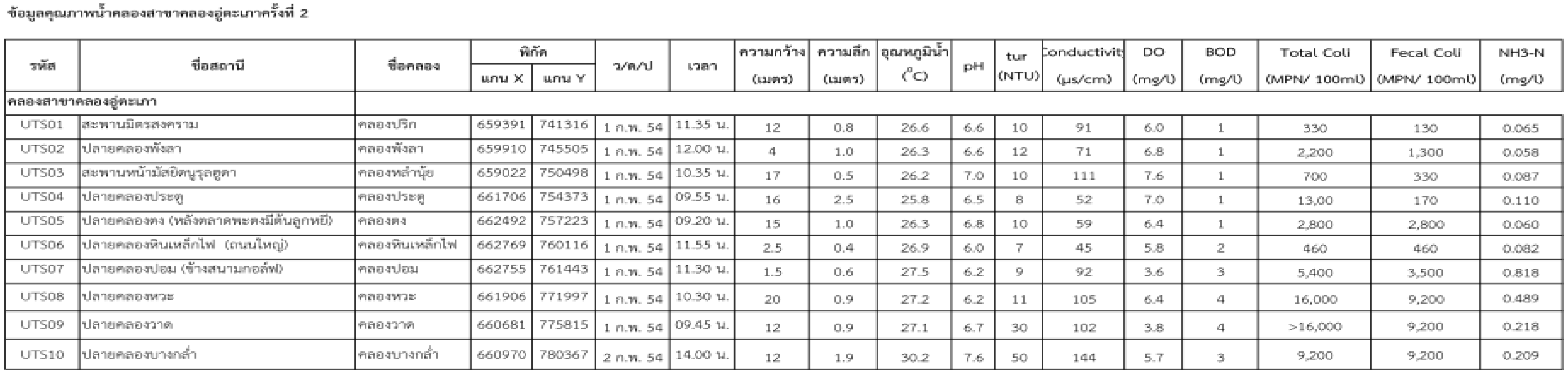


ข้อมูลคุณภาพน้ำคลองสาขาคลองอู่ตะเภาครั้งที่ 3/2554

รหัส	ชื่อสถานี	ชื่อคลอง	พิกัด		ความกว้าง (เมตร)	ความลึก (เมตร)	อุณหภูมิน้ำ (°C)	pH	tur(NTU)	Conductivity (µs/cm)	DO (mg/l)	BOD (mg/l)	Total Coli (MPN/ 100ml)	Fecal Coli (MPN/ 100ml)	NH3-N (mg/l)
			แกน X	แกน Y											
UTS01	สะพานมิตรสงคราม	คลองปริก	659391	741316	12	1.3	30.7	6.2	25	92	5.0	1.0	5,400	3,500	ND
UTS02	ปลายคลองพังลา	คลองพังลา	659910	745505	4	1.0	29.0	7.3	27	122	6.2	1.1	>1,600	1,600	0.005
UTS03	สะพานหน้ามัสยิดนูรุลฮูดา	คลองหล่ำนุ้ย	659022	750498	17	1.0	29.5	7.3	38	194	6.6	1.1	2,400	1,300	0.083
UTS04	ปลายคลองประตู	คลองประตู	661706	754373	16	1.0	27.8	7.0	66	137	6.0	2.4	5,400	1,100	0.146
UTS05	ปลายคลองตง (หลังตลาดพะตงมีต้นลูกหยี)	คลองตง	662492	757223	15	1.0	27.9	7.4	29	94	6.6	1.1	5,400	700	0.012
UTS06	ปลายคลองหินเหล็กไฟ (ถนนใหญ่)	คลองหินเหล็กไฟ	662769	760116	2.5	0.6	29.3	7.2	36	66	4.8	2.8	1,300	1,300	0.006
UTS07	ปลายคลองปอม (ข้างสนามกอล์ฟ)	คลองปอม	662755	761443	1.5	0.5	31.4	7.4	48	199	4.6	7.7	2,400	1,300	0.197
UTS08	ปลายคลองหวะ	คลองหวะ	661906	771997	20	0.8	30.05	6.5	44	94	5.4	5.4	16,000	9,200	0.123
UTS09	ปลายคลองวาด	คลองวาด	660681	775815	12	1.2	30.57	6.5	27	215	7.0	5.2	16,000	9,200	0.030
UTS10	ปลายคลองบางกล่ำ	คลองบางกล่ำ	660970	780367	12	0.8	30.3	7.5	32	257	3.4	3.7	790	790	0.154

ข้อมูลคุณภาพน้ำคลองอู่ตะเภาครั้งที่ 2

รหัส	ชื่อสถานี	ชื่อคลอง	พิกัด		ว/ด/ป	เวลา	ความกว้าง (เมตร)	ความลึก (เมตร)	อุณหภูมิน้ำ (°C)	pH	tur(NTU)	Conductivity (µs/cm)	DO (mg/l)	BOD (mg/l)	Total Coli (MPN/ 100ml)	Fecal Coli (MPN/ 100ml)	NH3-N (mg/l)
			แกน X	แกน Y													
คลองอู่ตะเภา																	
UT01	สะพานหลังวัดห้วยคู (บ้านท่าคลอง)	คลองสะเดา	664730	729095	2 ก.พ. 54	11.15 น.	10	0.5	26.6	6.7	75	43	6.2	14	16,000	16,000	0.099
UT02	สำนักงานประปาสะเดา	คลองสะเดา	659083	733842	2 ก.พ. 54	10.55 น.	20	0.8	26.1	6.8	70	53	6.6	1	2,200	2,200	0.055
UT03	หลังชุมชนมิตรสัมพันธ์ บริษัทสะเดา	คลองครอบ	655884	729678	2 ก.พ. 54	10.05 น.	2	0.3	25.3	7.6	10	537	3.8	3	2,400	1,300	0.282
UT04	สะพานข้างโรงเรียนแสนพงศ์	คลองครอบ	656722	733392	2 ก.พ. 54	10.20 น.	4	0.8	25.4	6.8	20	92	4.6	3	2,400	2,400	0.458
UT05	สะพานบ้านหน่ำสั้ว	คลองแห	654394	733327	2 ก.พ. 54	10.35 น.	20	0.8	25.6	6.8	10	95	4.6	4	2,400	2,400	0.353
UT06	หลังบริษัทเซฟสกิน	คลองแห	658130	736990	2 ก.พ. 54	11.45 น.	20	1.0	27.0	6.7	22	152	4.2	2	5,400	1,700	0.463
UT07	สะพานบ้านหัวถนน	คลองอู่ตะเภา	658774	737533	2 ก.พ. 54	12.05 น.	17	1.5	26.6	6.7	25	151	5.0	3	3,500	2,400	0.456
UT08	บ้านตะเคียนเภา (เข้าทางถนนมิตรสงคราม)	คลองอู่ตะเภา	658731	741088	1 ก.พ. 54	11.45 น.	22	1	26.7	6.7	24	153	5.1	4	1,100	1,100	0.256
UT09	สะพานบ้านท่าโพธิ์ออก (ถนนสุขาภิบาล 2 รร.กอบกุล)	คลองอู่ตะเภา	659883	749279	1 ก.พ. 54	11.00 น.	28	2.0	26.8	6.5	15	100	8.6	2	490	490	0.046
UT10	สะพานวัดม่วงก็อง	คลองอู่ตะเภา	659264	754133	1 ก.พ. 54	10.10 น.	15	1	26.4	6.7	17	99	4.3	2	490	330	0.078
UT11	สะพานบ้านพะตง (เข้าทางตลาดพะตง)	คลองอู่ตะเภา	662071	757846	1 ก.พ. 54	09.35 น.	50	2	26.9	6.8	9	128	5.0	3	9,200	9,200	0.062
UT12	สะพานหลังบ.สยามไฟเบอร์บอร์ด	คลองอู่ตะเภา	661236	759087	1 ก.พ. 54	12.10 น.	20	1.8	27.1	6.1	11	135	5.0	3	2,200	1,700	0.202
UT13	สะพานบ้านคลองปอม (เข้าทางถนนคลองปอม-ทุ่งลาน)	คลองอู่ตะเภา	661418	760892	1 ก.พ. 54	12.30 น.	20	1.8	27.1	6.1	15	122	5.0	2	16,000	16,000	0.161
UT14	สะพานโยธาธิการถ.คลองหลา-โคกหยอม	คลองอู่ตะเภา	661033	762692	1 ก.พ. 54	12.45 น.	24	1.2	27.1	6.3	18	113	4.8	2	>16,000	>16,000	0.190
UT15	สะพานวัดบางศาลา	คลองอู่ตะเภา	659416	766076	1 ก.พ. 54	11.15 น.	60	2.3	27.1	6.2	20	109	4.6	3	2,400	490	0.233
UT16	สะพานวิทยาลัยเมืองหาดใหญ่(จุดตัดถนนบายพาส)	คลองอู่ตะเภา	661984	771489	1 ก.พ. 54	10.50 น.	60	2.6	27.4	6.2	22	98	4.2	3	790	490	0.281
UT17	ปตร.คลองอู่ตะเภา	คลองอู่ตะเภา	661851	772341	1 ก.พ. 54	10.15 น.	90	3.5	27.8	6.3	21	98	4.6	2	400	210	0.280
UT18	สะพานทางเข้าวัดท่าแซ(จุดตัดถนนลพบุรีราเมศวร์)	คลองอู่ตะเภา	660804	777315	1 ก.พ. 54	09.25 น.	43	2.3	27.3	7.2	35	102	3.6	3	>16,000	>16,000	0.266
UT19	วัดนารังนก	คลองอู่ตะเภา	662471	781796	2 ก.พ. 54	13.40 น.	40	2.5	29.4	7.1	42	112	3.8	4	2,800	2,800	0.299
UT20	สะพานวัดคูเต่า	คลองอู่ตะเภา	662140	785665	2 ก.พ. 54	12.35 น.	62	2.9	29.1	7.2	30	123	3.5	3	790	490	0.286
UT21	สะพานสงขลาอาคูน่า	คลองอู่ตะเภา	661073	787729	2 ก.พ. 54	13.20 น.	76	3.2	29.5	7.6	26	137	6.3	9	330	330	0.280



ข้อมูลคุณภาพน้ำคลองสาขาคลองอู่ตะเภาครั้งที่ 2

รหัส	ชื่อสถานี	ชื่อคลอง	พิกัด		ว/ด/ป	เวลา	ความกว้าง (เมตร)	ความลึก (เมตร)	อุณหภูมิน้ำ (°C)	pH	tur (NTU)	Conductivit (µs/cm)	DO (mg/l)	BOD (mg/l)	Total Coli (MPN/ 100ml)	Fecal Coli (MPN/ 100ml)	NH3-N (mg/l)
			แกน X	แกน Y													
คลองสาขาคลองอู่ตะเภา																	
UTS01	สะพานมิตรสงคราม	คลองปริก	659391	741316	1 ก.พ. 54	11.35 น.	12	0.8	26.6	6.6	10	91	6.0	1	330	130	0.065
UTS02	ปลายคลองพังลา	คลองพังลา	659910	745505	1 ก.พ. 54	12.00 น.	4	1.0	26.3	6.6	12	71	6.8	1	2,200	1,300	0.058
UTS03	สะพานหน้ามัสยิดนูรุลฮูดา	คลองหลำนุ้ย	659022	750498	1 ก.พ. 54	10.35 น.	17	0.5	26.2	7.0	10	111	7.6	1	700	330	0.087
UTS04	ปลายคลองประดู	คลองประดู	661706	754373	1 ก.พ. 54	09.55 น.	16	2.5	25.8	6.5	8	52	7.0	1	13,00	170	0.110
UTS05	ปลายคลองตง (หลังตลาดพะตงมีต้นลูกหยี)	คลองตง	662492	757223	1 ก.พ. 54	09.20 น.	15	1.0	26.3	6.8	10	59	6.4	1	2,800	2,800	0.060
UTS06	ปลายคลองหินเหล็กไฟ (ถนนใหญ่)	คลองหินเหล็กไฟ	662769	760116	1 ก.พ. 54	11.55 น.	2.5	0.4	26.9	6.0	7	45	5.8	2	460	460	0.082
UTS07	ปลายคลองปอม (ข้างสนามกอล์ฟ)	คลองปอม	662755	761443	1 ก.พ. 54	11.30 น.	1.5	0.6	27.5	6.2	9	92	3.6	3	5,400	3,500	0.818
UTS08	ปลายคลองหวะ	คลองหวะ	661906	771997	1 ก.พ. 54	10.30 น.	20	0.9	27.2	6.2	11	105	6.4	4	16,000	9,200	0.489
UTS09	ปลายคลองวาด	คลองวาด	660681	775815	1 ก.พ. 54	09.45 น.	12	0.9	27.1	6.7	30	102	3.8	4	>16,000	9,200	0.218
UTS10	ปลายคลองบางกล่ำ	คลองบางกล่ำ	660970	780367	2 ก.พ. 54	14.00 น.	12	1.9	30.2	7.6	50	144	5.7	3	9,200	9,200	0.209

ข้อมูลคุณภาพน้ำคลองอู่ตะเภาครั้งที่ 1

รหัส	ชื่อสถานี	ชื่อคลอง	พิกัด		ความกว้าง	ความลึก	อุณหภูมิน้ำ	pH	tur(NTU)	Conductivity	DO	BOD	Total Coli	Fecal Coli	NH3-N
			แกน X	แกน Y	(เมตร)	(เมตร)	(°C)			(µs/cm)	(mg/l)	(mg/l)	(MPN/ 100ml)	(MPN/ 100ml)	(mg/l)
คลองอู่ตะเภา															
UT01	สะพานหลังวัดห้วยดู(บ้านท่าคลอง)	คลองสะเดา	664730	729095	10	2.0	26.0	7.1	256	21	7.2	2.3	1,300	1,300	0.021
UT02	สำนักงานประปาสะเดา	คลองสะเดา	659083	733842	20	2.5	26.1	7.3	357	32	6.0	3.5	24,000	13,000	0.029
UT03	หลังชุมชนมิตรสัมพันธ์ บริษัทสะเดา	คลองครอบ	655884	729678	2	0.5	27.9	6.8	10	165	4.4	6.5	240	240	0.682
UT04	สะพานข้างโรงเรียนเสนพงศ์	คลองครอบ	656722	733392	4	0.5	27.1	6.8	70	70	5.4	4.9	3,500	2,800	0.258
UT05	สะพานบ้านหน่ำฮั้ว	คลองเต่	654394	733327	20	2	26.8	6.8	288	39	4.6	3.4	92,000	54,000	0.140
UT06	หลังบริษัทเซฟสกิน	คลองเต่	658130	736990	20	3.0	28.2	6.8	230	42	5.6	4.7	7,900	7,900	0.087
UT07	สะพานบ้านหัวถนน	คลองอู่ตะเภา	658774	737533	17	8	26.6	6.7	292	40	5.0	3.4	160,000	160,000	0.109
UT08	บ้านตะเคียนเภา (เข้าทางถนนมิตรสงคราม)	คลองอู่ตะเภา	658731	741088	22	3	27.1	6.7	219	38	4.6	2.4	23	23	0.061
UT09	สะพานบ้านท่าโพธิ์ออก (ถนนสุขาภิบาล 2 รร.กอบกุล)	คลองอู่ตะเภา	659883	749279	28	1.5	27.6	7.2	153	51	4.6	2.3	1,300	1,300	0.060
UT10	สะพานวัดม่วงก็อง	คลองอู่ตะเภา	659264	754133	15	3	27.5	7.1	128	57	5.2	3.7	16,000	16,000	0.072
UT11	สะพานบ้านพะตง (เข้าทางตลาดพะตง)	คลองอู่ตะเภา	662071	757846	50	3	27.5	6.9	113	58	5.0	1.5	2,400	790	0.059
UT12	สะพานหลังบ.สยามไฟเบอร์บอร์ด	คลองอู่ตะเภา	661236	759087	20	3	27.3	7.4	150	52	7.5	3.3	16,000	5,400	0.061
UT13	สะพานบ้านคลองปอม (เข้าทางถนนคลองปอม-ทุ่งลาน)	คลองอู่ตะเภา	661418	760892	20	3	27.4	7.1	159	53	7.5	2.5	1,400	1,400	0.056
UT14	สะพาน โยธาธิการถ.คลองหลา-โคกหยอม	คลองอู่ตะเภา	661033	762692	15	1.9	27.5	6.6	149	55	4.9	5.3	20,000	9,200	0.077
UT15	สะพานวัดบางศาลา	คลองอู่ตะเภา	659416	766076	16	2.8	27.5	6.5	144	53	6.5	2.1	9,200	5,400	0.065
UT16	สะพานวิทยาลัยเมืองหาดใหญ่(จุดตัดถนนบายพาส)	คลองอู่ตะเภา	661984	771489	10	2.7	27.8	6.6	121	53	5.5	2.0	9,200	5,400	0.064
UT17	ปตร.คลองอู่ตะเภา	คลองอู่ตะเภา	661851	772341	90	3.5	28.0	6.8	134	54	5.6	0.8	20,000	20,000	0.100
UT18	สะพานทางเข้าวัดท่าแซ(จุดตัดถนนลพบุรีราเมศวร์)	คลองอู่ตะเภา	660804	777315	12	2.3	28.3	6.1	97	63	5.0	2.3	16,000	16,000	0.147
UT19	วัดนารังนก	คลองอู่ตะเภา	662471	781796	40	2.5	28.7	6.1	83	61	5.1	1.3	3,500	3,500	0.138
UT20	สะพานวัดคูเต่า	คลองอู่ตะเภา	662140	785665	62	2.9	28.6	6.2	72	67	4.4	2.6	20,000	20,000	0.193
UT21	สะพานสงขลาลาญน่า	คลองอู่ตะเภา	661073	787729	76	3.2	29.2	7.1	95	70	4.7	3.6	20,000	20,000	0.180

ข้อมูลคุณภาพน้ำคลองสาขาคลองอู่ตะเภา

รหัส	ชื่อสถานี	พิกัด		ความกว้าง (เมตร)	ความลึก (เมตร)	อุณหภูมิน้ำ (°C)	pH	tur(NTU)	Conductivity (µs/cm)	DO (mg/l)	BOD (mg/l)	Total Coli (MPN/ 100ml)	Fecal Coli (MPN/ 100ml)	NH3-N (mg/l)
		แกน X	แกน Y											
คลองสาขาคลองอู่ตะเภา														
UTS01	สะพานมิตรสงคราม	659391	741316	12	1.5	27.3	6.8	206	59	6	4.3	20,000	3500	0.059
UTS02	ปลายคลองพังลา	659910	745505	4	1.0	27.1	7.6	7	62	6.8	2.4	2,200	2,200	0.064
UTS03	สะพานหน้ามัสยิดนูรุลฮูดา	659022	750498	17	2.0	27.4	7.2	134	57	5.2	2.4	5,400	5,400	0.077
UTS04	ปลายคลองประดู่	661706	754373	16	2.0	27.3	7.8	235	60	6.2	2.6	1,300	1300	0.122
UTS05	ปลายคลองตง (หลังตลาดพะตงมีต้นลูกหยี)	662492	757223	15	3.0	27.0	7.1	169	47	6.6	1.4	20,000	20,000	0.052
UTS06	ปลายคลองหินเหล็กไฟ (ถนนใหญ่)	662769	760116	7	0.5	27.7	8.0	40	54	5.6	2.5	16,000	16,000	0.114
UTS07	ปลายคลองปอม (ข้างสนามกอล์ฟ)	662755	761443	1.5	0.5	27.9	7.7	32	54	4.6	2.8	16,000	5,400	0.326
UTS08	ปลายคลองหวะ	661906	771997	15	1.2	28.8	6.6	44	71	6.2	3.7	20,000	20,000	0.266
UTS09	ปลายคลองวาด	660681	775815	12	1.3	29.2	6.1	47	67	7.7	3.4	2,400	2,400	0.170
UTS10	ปลายคลองบางกล่ำ	660970	780367	12	1.9	28.5	6.1	65	79	4.0	3.5	9,200	9,200	0.133

ข้อมูลคุณภาพน้ำคลองอู่ตะเภา

รหัส	ชื่อสถานี	ชื่อคลอง	พิกัด		ความกว้าง (เมตร)	ความลึก (เมตร)	อุณหภูมิน้ำ (°C)				pH				Conductivity (µs/cm)				DO (mg/l)				BOD (mg/l)			
			แกน X	แกน Y																						
คลองอู่ตะเภา							พ.ย.	ก.พ.	พ.ค.	ส.ค.	พ.ย.	ก.พ.	พ.ค.	ส.ค.	พ.ย.	ก.พ.	พ.ค.	ส.ค.	พ.ย.	ก.พ	พ.ค.	ส.ค.	พ.ย.	ก.พ.	พ.ค.	ส.ค.
UT01	สะพานหลังวัดห้วยลึก(บ้านท่าคลอง)	คลองสะเดา	664730	729095	10	0.6	27.1	27.7	30.5	27.6	6.6	7.4	7.7	8.2	10	15	26	31	6.4	5.6	5.2	6.8	1.8	1.9	2.4	1.6
UT02	สำนักงานประปาสะเดา	คลองสะเดา	659083	733842	20	1.3	27.5	27.7	30.1	27.4	6.2	7.5	8.0	8.9	18	17	41	52	5.8	6.2	5.6	6.6	1.8	1.9	1.5	1
UT03	หลังชุมชนมิตรสัมพันธ์ บริษัทสะเดา	คลองครอบ	655884	729678	2	0.3	29.2	28.8	31.9	28.1	6.3	8.1	7.5	7.7	212	1350	616	670	4.4	5.2	2.4	4.2	3.6	3.8	8.2	3.5
UT04	สะพานข้างโรงเรียนแสนพงศ์	คลองครอบ	656722	733392	4	0.4	28.0	27.0	29.9	27.8	6.3	8.2	7.3	7.6	31	130	298	167	5.6	6.6	3.2	3.6	3.6	5.2	2.4	2.1
UT05	สะพานบ้านหน้าถ้ำ	คลองเต่	654394	733327	20	0.8	27.6	27.8	30.0	28.5	6.4	7.4	7.3	7.5	41	83	110	156	4.4	4.0	4.0	4.4	2.9	5.1	3.2	1.5
UT06	หลังบริษัทเซฟสกิน	คลองเต่	658130	736990	20	1.5	26.8	29.0	31.8	28.2	6.9	7.4	7.4	7.4	27	92	74	268	4.2	5.6	5.4	5.6	6.3	1.9	4.9	3.9
UT07	สะพานบ้านหัวถนน	คลองอู่ตะเภา	658774	737533	17	1.2	27.6	28.4	30.8	28.0	6.2	7.4	7.2	7.2	52	92	68	126	4.6	5.4	5.4	5.6	1.3	2.1	2.4	0.7
UT08	สงคราม)	คลองอู่ตะเภา	658731	741088	22	1.6	27.8	28.5	31.0	28.9	6.5	7.4	6.8	6.9	45	78	65	132	3.8	4.2	4.8	3.8	2.7	3.6	2.2	3.2
UT09	2 รร.กอบกุล)	คลองอู่ตะเภา	659883	749279	28	1.4	27.5	29.4	30.0	28.3	6.3	8.0	6.9	7.3	42	64	74	138	3.8	5.0	4.2	4.4	3.4	2.8	4.3	4.4
UT10	สะพานวัดม่วงก็อง	คลองอู่ตะเภา	659264	754133	15	1.5	28.1	29.8	30.7	28.8	6.9	7.4	6.9	7.3	47	68	75	162	4.2	5.8	5.2	4.0	3.5	1.4	3	2.7
UT11	สะพานบ้านพะตง (ข้างทางตลาดพะตง)	คลองอู่ตะเภา	662071	757846	50	2.0	28.0	30.1	31.8	29.8	6.5	7.1	6.8	7.0	53	130	185	203	2.8	4.4	4.6	4.4	5.4	1.6	3.8	4.5
UT12	สะพานหลังบ.สยามไฟเบอร์บอร์ด	คลองอู่ตะเภา	661236	759087	20	2.0	27.8	28.9	31.3	28.5	5.9	6.5	6.9	8.5	96	231	196	158	3.0	4.2	3.6	4.0	1.6	5.1	4.5	1.8
UT13	คลองปอม-ทุ่งตาน)	คลองอู่ตะเภา	661418	760892	20	2.0	28.2	29.4	32.5	29.5	5.8	7.1	6.5	8.1	69	233	267	146	2.6	3.2	3.8	5.0	3.3	2.3	6	5.4
UT14	สะพานโยธาธิการอ.คลองหลา-โคกหยอม	คลองอู่ตะเภา	661033	762692	15	1.8	28.6	29.4	32.9	29.4	5.8	7.2	6.2	8.4	94	218	250	154	2.8	3.2	4.6	4.2	3.8	3.8	5.5	1.6
UT15	สะพานวัดบางศาลา	คลองอู่ตะเภา	659416	766076	16	1.5	27.7	29.6	33.7	28.8	6.1	6.9	6.3	8.1	99	200	277	145	3.2	3.8	3.8	3.8	1.5	4.1	5.6	2.6
UT16	ถนนบายพาส)	คลองอู่ตะเภา	661984	771489	10	2.0	28.9	31.0	33.8	28.7	5.6	7.1	7.9	8.1	82	185	323	161	2.6	6.0	6.4	3.2	2.2	3.0	7.7	0.8
UT17	ปตร.คลองอู่ตะเภา	คลองอู่ตะเภา	661851	772341	90	2.0	29.5	31.8	34.0	29.8	5.77	7.5	8	7.8	92	188	314	194.6	3.4	6.2	4.8	2.6	2.7	3.1	8.2	2
UT18	สะพานทางเข้าวัดท่าแซ(จุดตัดถนน ลพบุรีราเมศวร์)	คลองอู่ตะเภา	660804	777315	12	3.0	29.3	30.7	31.0	29.0	4.9	6.8	9.2	8.7	46	193	1041	284	2.6	2.4	4	3.2	2.8	2	7.8	6.1
UT19	วัดนารังนก	คลองอู่ตะเภา	662471	781796	40	1.5	29.2	30.9	32.5	30.2	5.8	6.9	8.7	8.4	95	190	4049	306.6	3.6	4.8	4	1.4	3.6	5.3	6.7	2.1
UT20	สะพานวัดคูเต่า	คลองอู่ตะเภา	662140	785665	62	2.5	29.0	30.1	32.6	30.2	5.8	6.86	8.2	8.6	98	190	13253	401.5	3.4	4.2	7	2.2	4.5	4.4	4.5	4.3
UT21	สะพานสงขลาอาภูน่า	คลองอู่ตะเภา	661073	787729	76	3.0	30.0	30.3	31.0	30.9	5.8	7.83	8.6	8.6	117	226	15064	14.18	2.4	3.8	6	2.8	3.3	2.7	6	3.8
คลองสาขาคลองอู่ตะเภา																										
UTS01	สะพานมิตรสงคราม	คลองปริก	659391	741316	12	1.3	28.3	30.4	32.9	29.95	6.7	7.3	6.9	7.1	33	61	87	128	6.0	4.8	3.8	5.0	1.3	2.0	4.9	1.4
UTS02	ปลายคลองพังลา	คลองพังลา	659910	745505	4	0.8	27.5	30	29	29.5	6.4	7.3	6.7	7.6	37	69	87	89	4.0	6.0	1.8	6.0	3.6	3.0	3.1	1.1
UTS03	สะพานหน้ามัสยิดนูรุลฮูดา	คลองหลำเบ้ย	659022	750498	17	1.3	27.6	30.7	29.1	28.9	7.0	8.2	7.6	7.4	50	87	95	116	5.6	6.8	6.4	6.0	4.5	3.1	2.2	0.8
UTS04	ปลายคลองประดู่	คลองประดู่	661706	754373	16	0.9	27.3	29.8	30.3	29	6.3	7.1	6.8	8.0	39	140	68	139	6.0	6.8	5.2	6.0	4.3	1.5	1.8	1.4
UTS05	หยี)	คลองตง	662492	757223	15	1	28.1	29.1	23.4	28.6	6.6	7.1	6.5	7.1	32	42	70	103	5.4	6.8	4.9	4.0	4.5	0.8	3.3	2.4
UTS06	ปลายคลองหินเหล็กไฟ (ถนนใหญ่)	คลองหินเหล็กไฟ	662769	760116	7	0.5	27.5	27.76		28.6	5.9	6.4		8.5	59	45		58	5.4	6.6		6.2	1.2	1.9	-	3.8
UTS07	ปลายคลองปอม (ข้างสนามกอล์ฟ)	คลองปอม	662755	761443	1.5	0.5	28.6	29.52	31.26	29.4	6.2	7.7	6.4	8.0	79	155	745	325	3.4	4.6	0.6	1.8	2.8	2.5	7.8	3.8
UTS08	ปลายคลองหวะ	คลองหวะ	661906	771997	15	0.5	29.9	31.8	33.75	29	6.0	7.0	6.8	8.1	110	292	464	589	5.0	5.2	7.2	3.8	2.0	8.9	8.5	5.2
UTS09	ปลายคลองวาด	คลองวาด	660681	775815	12	0.5	30.6	30.63	33.2	29.3	5.16	7.51	7.9	8.1	1	210	514	321.1	1	3.2	4.8	1.8	3.3	1.5	5.9	4.3
UTS10	ปลายคลองบางกล่ำ	คลองบางกล่ำ	660970	780367	12	1	29	30.8	32.95	32.4	5.8	7.8	8.1	8.4	50	273	3554	227.8	3	3.8	5	4.6	3.7	2.1	5.1	3.3

ข้อมูลคุณภาพน้ำคลองอู่ตะเภา ปีงบประมาณ 2552

รหัส	ชื่อสถานี	ชื่อคลอง	พิกัด		อุณหภูมิน้ำ (°C)			pH			Conductivity(μs/cm)			DO (mg/l)			BOD (mg/l)		
			แกน X	แกน Y	พ.ย.	ก.พ.	พ.ค.	พ.ย.	ก.พ.	พ.ค.	พ.ย.	ก.พ.	พ.ค.	พ.ย.	ก.พ.	พ.ค.	พ.ย.	ก.พ.	พ.ค.
UTC01	บ้านท่าคลอง (วัดหัวยคู)	คลองสะเดา	664730	729095	26.2	26.5	28	6.58	6.5	6.5	45.8	40	45	6.7	7	6.6	0.5	0.7	1.3
UTC02	หลังโรงงานสะเดาอุตสาหกรรม	คลองครอบ	655884	729678	-	-	28	-	-	7.0	-	-	508	-	-	5.0	-	-	3.9
UTC03	โรงเรียนเสนพงศ์	คลองครอบ	656722	733392	-	-	28	-	-	6.6	-	-	141	-	-	6.2	-	-	2.7
UTC04	บ้านหน่ำสั้ว	คลองเล่	654394	733327	26.6	27	27	6.39	7	6.4	72	151	81	4.3	3	4.6	2.1	3.5	3.7
UTC05	สำนักงานประปาสะเดา	คลองสะเดา	659083	733842	25.9	27	27	6.51	6	6.1	61.1	45	42	6	6	5.0	0.6	1.9	2.0
UTC06	ปลายคลองเล่ ต.พังลา	คลองเล่	658130	736990	26.6	27.6	27	6.38	6.5	6.3	73.8	104	100	3.4	2.8	2.8	3.1	2.3	2.3
UTC07	บ้านหัวถนน	คลองอู่ตะเภา	658774	737533	26.6	27.3	27	6.35	5	4.4	102.3	141	78	4	3.6	4.0	2.4	3.3	1.8
UTC08	บ้านตะเคียนเภา	คลองอู่ตะเภา	658731	741088	-	-	27	-	-	6.3	-	-	100	-	-	3.6	-	-	4.4
UTC09	สะพานมิตรสงคราม	คลองปริก	659391	741316	29.1	28.5	29	6.67	6	6.4	106.5	106	63	5.2	2	6.0	0.9	2.5	3.3
UTC10	หลังบริษัทเซฟสกิน อ.สะเดา	คลองพังลา	659910	745505	26.8	28.3	26.6	11.4	7	6.4	127.6	103	58	5.2	3.8	6.0	2.7	2.0	2.4
UTC11	บ้านท่าโพธิ์ออก	คลองอู่ตะเภา	659883	749279	-	-	27.5	-	-	6.3	-	-	87	-	-	3.8	-	-	3.4
UTC12	บ้านคลองแงะ ต.คลองแงะ	คลองหล้านุ้ย	659022	750498	26.5	29	27.3	12.5	7.5	6.7	97.5	129	70	5.8	4.6	5.4	0.9	1.2	3.6
UTC13	บ้านม่วงก็อง อ.สะเดา	คลองอู่ตะเภา	659264	754133	-	-	27	-	-	6.5	-	-	78	-	-	4.4	-	-	3.2
UTC14	ปลายคลองประตู	คลองประตู	661706	754373	27.1	26.4	26.8	6.3	5	6.1	191.8	147	73	6	6.8	6.4	1	1.3	3.7
UTC15	ปลายคลองตง ต.พะตง	คลองตง	662492	757223	27.8	29.3	26.3	13.1	5	6.3	86.7	75	38	5.8	4.4	6.8	1.4	1.6	2.3
UTC16	บ้านพะตง ต.พะตง	คลองอู่ตะเภา	662071	757846	-	-	27	-	-	6.5	-	-	107	-	-	5.0	-	-	2.2
UTC17	หลังโรงงานสยามไฟเบอร์บอร์ด	คลองอู่ตะเภา	661236	759087	-	-	27.3	-	-	6.5	-	-	74	-	-	4.6	-	-	2.5
UTC18	ปลายคลองหินเหล็กไฟ	คลองหินเหล็กไฟ	662769	760116	26.3	27	27	6.5	6	6.0	62.5	60	53	6.8	6.4	6.4	1	0.9	2.0
UTC19	บ้านคลองปอม อ.หาดใหญ่	คลองอู่ตะเภา	661418	760892	-	-	27.6	-	-	6.5	-	-	75	-	-	3.6	-	-	4.6
UTC20	ปลายคลองปอม บ้านไร่	คลองปอม	662755	761443	28.2	28.8	29	7.1	6.6	6.3	254.5	175	139	0.8	3.6	3.0	3.1	3.3	5.2
UTC21	สะพานโยธาธิการ ถนนคลองพลา-โคกพะยอม	คลองอู่ตะเภา	661033	762692	27.8	29	27	13.5	6.8	6.6	133.3	277	94	5	3.8	4.7	1.1	3.7	2.7
UTC22	วัดบางศาลา ต.บ้านพรุ	คลองอู่ตะเภา	659416	766076	28.4	30.2	27.4	13.5	6.8	6.4	126.4	242	75	4.8	3.6	4.5	0.8	3.6	2.9
UTC23	สะพารวิทยาลัยเมืองหาดใหญ่	คลองอู่ตะเภา	661984	771489	28.6	29.43	28.4	5.5	6.7	6.6	90	117	80	3.6	4	4.6	2.7	5.1	2.4
UTC24	ปลายคลองหวะ	คลองหวะ	661906	771997	29.6	30	29.17	5.7	6.9	6.8	293	298	176	1.8	4.9	5.2	2.4	6.1	3.2
UTC25	ปตร.อู่ตะเภา	คลองอู่ตะเภา	661851	772341	28.6	32.7	28.43	5.6	7.7	6.41	94	228	83	4.2	11.2	3.7	2.7	5.5	2.6
UTC26	ปลายคลองวาด	คลองวาด	660681	775815	29.7	30	30.8	5.89	6.5	6.65	432	235	157	1.5	3.1	3.8	2.7	2.4	2
UTC27	จุดตัดถนนลพบุรีราเมศวร์ ทางเข้าวัดท่าแซ	คลองอู่ตะเภา	660804	777315	28.5	31.8	29.11	5.67	6.6	6.34	93	206	98	3.9	4.4	4	2.5	3.3	2.3
UTC28	ปลายคลองบางกล่ำ	คลองบางกล่ำ	660970	780367	30.9	30.9	29.33	5.97	6.6	6.77	100	217	94	3.6	3.4	4.2	1.2	3.6	2.3
UTC29	วัดนารังนก	คลองอู่ตะเภา	662471	781796	-	-	29.14	-	-	6.4	-	-	121	-	-	3.6	-	-	2.4
UTC30	สะพานวัดคูเต่า ต.คูเต่า	คลองอู่ตะเภา	662140	785665	28.9	31	29.7	6.1	6.5	6.57	150	214	142	2.2	3.8	3.4	2.6	3.1	2.9
UTC31	สะพานสงขลาลากูน่า ต.บางหยี	คลองอู่ตะเภา	661073	787729	29.3	31.6	30.2	6.4	6	6.67	153	234	160	2.2	5.4	3.9	0.8	2.5	2.6

เก็บตัวอย่างน้ำ ครั้งที่ 1 วันที่ 14 พ.ย. 2551 ,ครั้งที่ 2 วันที่ 13 ก.พ. 2552 และครั้งที่ 3 วันที่ 18-19 พ.ค. 2552

คุณภาพน้ำคลองอู่ตะเภา ปี 2551

รหัส	ชื่อสถานี	พิกัด		ความกว้าง	ความลึก (เมตร)						อุณหภูมิน้ำ (^{0}C)						pH						Conductivity (µS/cm)						DO (mg/l)						BOD (mg/l)					
		แกน X	แกน Y	(เมตร)	ม.ค.	มี.ค.	พ.ค.	ก.ค.	ก.ย.	พ.ย.	ม.ค.	มี.ค.	พ.ค.	ก.ค.	ก.ย.	พ.ย.	ม.ค.	มี.ค.	พ.ค.	ก.ค.	ก.ย.	พ.ย.	ม.ค.	มี.ค.	พ.ค.	ก.ค.	ก.ย.	พ.ย.	ม.ค.	มี.ค.	พ.ค.	ก.ค.	ก.ย.	พ.ย.	ม.ค.	มี.ค.	พ.ค.	ก.ค.	ก.ย.	พ.ย.
UTC01	บ้านหัวถนน	658774	737533	10	1	1	2	2	2.5	2.5	26	27	28	29	27	26.6	6.74	6.65	6.21	6.6	6.7	6.4	0.17	182	109	99	118	102	4.8	4.4	4.5	4.6	3.2	4.0	2.88	1.26	3.70	2.5	2.9	2.4
UTC02	สะพานโยธาธิการ คลองพลา-โคกพะยอม	661033	762692	18	2	2	2	2	1.5	1.5	26	28	29	29	28	27.8	6.57	7.35	7.71	7.6	6.8	6.8	0.06	239	137	167	159	133	3.8	4	4	3.4	3.8	5.0	2.20	2.10	2.93	1.7	2.9	1.1
UTC03	พรุค้างคาว	660224	765856	28	2	2	1.9	2.5	1.4	1.5	27	28	29	29	28	28.2	6.58	7.34	7.64	7.7	6.8	6.7	0.13	270	135	175	164	130	3.4	3.8	5.2	3.4	3.6	4.8	1.83	3.18	2.11	1.7	2.7	0.7
UTC04	วัดบางศาลา	659416	766076	30	2	5	1.9	2	1.5	1.6	27	28	29	29	28	28.4	6.61	7.43	7.74	7.7	6.8	6.9	0.13	240	132	148	151	126	3.6	4.2	5	4.4	4.0	4.8	5.40	4.90	3.05	2.8	4.8	0.8
UTC05	จุดตัดถนนบายพาส ม.หาดใหญ่	661984	771489	40	0.8	0.8	1.3	1.3	1.3	1.2	26	28	29	29	29	28.6	8.75	6.96	7.7	6.6	7.5	5.5	121	220	136	149	144	90	3.8	2.2	4.2	3.5	3.4	3.6	5.42	5.21	2.34	2.1	4.9	2.7
UTC06	ปตร.อู่ตะเภา	661851	772341	90	3	3	3	3	3	0.5	27	29	29	30	29	28.6	8.84	7.2	7.43	7.4	7.2	5.6	122	219	125	147	160	94	4.2	2.7	4.2	4.4	3.4	4.2	3.76	5.18	2.22	1.6	2.7	2.7
UTC07	จุดตัดถนนลพบุรีราเมศวร์ ทางเข้าวัดท่าแซ	660804	777315	35	2.5	4	2	2	2	3.5	27	29	30	30	29	28.5	6.02	6.95	7.23	6.4	7.4	5.7	124	212	142	148	181	93	3.6	1.4	3.9	3.0	2.4	3.9	4.99	3.79	3.85	2.3	3.2	2.5
UTC08	สะพานวัดคูเต่า	662140	785665	50	2.2	2.2	2	2	2	2.5	28	29	30	30	30	28.9	8.71	6.88	5.99	5.9	7.3	6.1	153	227	134	166	177	150	2	1.4	2.6	2.1	1.4	2.2	4.96	3.18	2.56	2.6	3.2	2.6
UTC09	สะพานสงขลาลาคูน่า	661073	787729	40	1.8	1.8	2	2	2	2.5	28	29	31	30	30	29.3	9.24	6.88	5.97	5.7	7.2	6.4	159	304	133	167	165	153	2.2	2	2.2	2.4	1.2	2.2	5.29	4.50	4.02	4.8	4.0	0.8

หมายเหตุ : เก็บตัวอย่างเมื่อวันที่ 3 มกราคม, 5 มีนาคม ,16 พฤษภาคม, 4 กรกฎาคม, 5 กันยายน 2551 และ 4 พฤศจิกายน 2551

คุณภาพน้ำคลองอู่ตะเภา ปี 2550

รหัส	ชื่อสถานี	พิกัด		ความกว้าง (เมตร)	ความลึก (เมตร)				อุณหภูมิน้ำ (^{o}C)				pH				Conductivity (µS/cm)				DO (mg/l)				BOD (mg/l)			
		แกน X	แกน Y		พ.ค.	ก.ค.	ก.ย.	พ.ย.	พ.ค.	ก.ค.	ก.ย.	พ.ย.	พ.ค.	ก.ค.	ก.ย.	พ.ย.	พ.ค.	ก.ค.	ก.ย.	พ.ย.	พ.ค.	ก.ค.	ก.ย.	พ.ย.	พ.ค.	ก.ค.	ก.ย.	พ.ย.
UTC01	หลังบ.เซฟสกิน เมดิคอล	658774	737533	10	0.8	2.0	2.0	2.0	30	29	28	28	6.7	5.5	6.9	5.9	0.23	0.09	0.09	0.00	2.4	3.8	4.8	3.1	4.1	2.6	4.8	11.6
UTC02	สะพานโยธาธิการ คลองพลา-โคกพะยอม	661033	762692	18	1.0	0.5	0.5	6.0	30	31	29	26	6.1	5.8	6.7	6.4	0.27	0.16	0.14	0.38	1.8	2.3	3.6	3.2	16.2	6.8	2.6	9.6
UTC03	สะพานบ้านพรุธานี	660224	765856	28	2.1	1.5	1.5	5.0	31	31	29	27	5.6	4.6	5.3	6.5	0.25	0.19	0.15	0.19	2.0	2.7	2.8	3.0	7.9	3.3	2.2	12.3
UTC04	สะพานวัดบางศาลา	659416	766076	30	2.8	2.2	2.2	5.0	31	31	29	27	6.2	4.8	6.8	7.0	0.24	0.17	0.14	0.14	1.8	3.8	2.4	3.0	9.6	3.0	2.3	11.0
UTC05	จุดตัดถนนบายพาส ม.หาดใหญ่	661984	771489	40	4.8	3.5	3.5	2.5	33	32	29	28	6.7	5.0	6.4	7.1	0.18	0.17	0.16	0.11	1.4	2.6	2.5	2.2	14.8	1.8	2.0	1.9
UTC06	ปตร.อู่ตะเภา	661851	772341	90	3.0	2.7	2.7	2.7	31	33	31	27	5.8	6.0	5.7	8.4	0.18	0.17	0.17	0.09	2.7	4.5	2.8	2.6	9.1	4.8	2.0	2.1
UTC07	จุดตัดถนนลพบุรีราเมศวร์ ทางเข้าวัดท่าแซ	660804	777315	35	3.5	3.0	3.0	2.5	32	31	30	28	5.5	6.5	4.9	7.5	0.18	0.17	0.17	0.09	1.0	2.0	2.5	2.4	13.3	3.8	1.7	6.5
UTC08	สะพานวัดคูเต่า	662140	785665	50	3.6	3.0	3.0	2.2	32	30	29	28	5.7	4.6	5.6	6.3	0.58	0.18	0.20	0.13	1.2	2.0	2.0	1.8	7.6	5.0	1.1	2.9
UTC09	สะพานสงขลาลากูน่า	661073	787729	40	4.7	4.5	4.5	4.0	31	30	30	29	6.1	5.2	4.6	7.9	1.70	1.94	0.25	0.14	0.5	1.8	1.5	1.0	15.4	2.7	0.9	2.6

หมายเหตุ : เก็บตัวอย่างเมื่อวันที่ 14-16 พฤษภาคม, 2-4 กรกฎาคม, 3-6 กันยายน และ 1 พฤศจิกายน 2550

Appendix D

Land use classification

Level 1		Level 2		Level 3	
U	Urban and build up land	U1	City, town and commercial land		
		U2	Village		
		U3	Institution land		
		U4	Transportation land		
		U5	Industrial land		
		U6	Others		
A	Agricultural land	A1	Paddy field	A1.1	Transplanted Paddy Field
				A1.2	Broadcasted Paddy Field
				A1.3	Abandoned
		A2	Field Crops	A2.1	Mixed Fied Crops
				A2.2	Corn
				A2.3	Sugar cane
				A2.4	Cassava
				A2.5	Pine apple
				A2.7	Tobacco
				A2.8	Mungbean
				A2.9	Soybean
				A2.10	Peanut
				A2.11	Kenaf
				A2.12	Jute
				A2.13	Sorgbun
				A2.14	Castor bean
				A2.15	Sesane
				A2.16	Upland rice
				A2.17	Irish potato
				A2.18	Jan potato
				A2.19	Sweet potato
				A2.20	Watermelon
				A2.21	Others
		A3	Perennial crops	A3.1	Mixed perennial crops
				A3.2	Para rubber
				A3.3	Oil palm
				A3.4	Kapok
				A3.5	Coffee
				A3.6	Tea
				A3.7	Bamboo
				A3.8	Mulberry
				A3.9	Eucalytus
				A3.10	Casurina
				A3.11	Others

Land use classification (continued)

Level 1	Level 2		Level 3	
	A4	Orchard	A4.1	Mixed orchard
			A4.2	Citrus
			A4.3	Durian
			A4.4	Ranbutan
			A4.5	Coconut
			A4.6	Litchi
			A4.7	Mango
			A4.8	Cashev
			A4.9	Jujube
			A4.10	Castard apple
			A4.11	Banana
			A4.12	Tanarind
			A4.13	Longan
			A4.14	Mango
			A4.15	Others
	A5	Horticulture	A5.1	Mixed horticultur
			A5.2	Truck crops
			A5.3	Oruck crops
			A5.4	Vineyard
			A5.5	Pepper
			A5.6	Others
	A6	Swidden cultivation	A6.1	Upland rice
			A6.2	Corn
			A6.3	Beans and peas
			A6.4	Sesane
			A6.5	Potatoes
			A6.6	Truck crops
			A6.7	Opium poppy
			A6.8	Preparatpry land for fied crops
			A6.9	Bush fallow
			A6.10	Others
	A7	Pasture		
	A8	Animal farm houses	A8.1	Mixed animal farm houses
			A8.2	Poultry
			A8.3	Seine
			A8.4	Livestock
			A8.5	Others
	A9	Fishery	A9.1	Fish farm
			A9.2	Shrimp farm
			A9.3	Crab farm
			A9.4	Others

Land use classification (continued)

Level 1		Level 2		Level 3	
		A10	Aquatic plants	A10.1	Reed
				A10.2	Water Chest
				A10.3	Water chestnut
F	Forest land	F1	Evergreen forest	F1.1	Tropical rain forest
				F1.2	Dry evergreen forest
				F1.3	Hill evergreen forest
				F1.4	Coniferous forest
				F1.5	Banvoo forest
				F1.6	Fresh water seamp forest
				F1.7	Mangrove seamp forest
				F1.8	Beach forest
				F1.9	Others
		F2	Deciduous forest	F2.1	Mixed deciduous forest
				F2.2	Dry dipterocarp forest
				F2.3	Bamboo forest
		F3	Forest plantation	F3.1	Teak plantation
				F3.2	Coniferous plantation
				F3.3	Bucalyptus plantation
				F3.4	Others
		F4	Disturbed forest		
W	Water body	W1	Natural water resources	W1.1	Grass land
				W1.2	Bush and shrubs
		W2	Wet land	W2.1	Swamp
				W2.2	Marsh
		W3	Mines	W3.1	Operating
				W3.2	Abandoned
		W4	Salt pan		
		W5	Rocky		
		W6	Beach and sand bar		
		M8	Others		

Source: Division of land use planning, Department of land use survey, May 2533.

APPENDIX E

Land use suitability analysis of agriculture (rubber)

Factor	Land use requirement			Factor rating			
	Land quality	Factor	Unit	S1	S2	S3	N
Bio-physical	Climate	Mean temp	^{0}C	20-30	31-33, 19-17	33-35, 16-15	>35,<15
Bio-physical	Climate	Annual rainfall	mm	1500-2000	2500-4500 1200-1500	4500-5000 1100-1200	>5000 <1100
Bio-physical	Topography	Slope	class	A,B,C/ Flat, slightly slope 0-2, 2-5, 5-12	D slight slope 12-20	E Slope 20-35	>E Higher slope >35
Bio-physical	Elevation	Altitude	m	0-100	100-1000	1000-2000	>2000
Bio-physical	Soil	pH value	pH	5.6-6.5	6.6-7.8 5.1-5.5	7.9-8.4 4.5-5.0	>8.4 <4.5
Bio-physical	Soil	drainage	class	Well drained/ Excessively drained	Moderately well drained	Somewhat poorly drained	Poorly drained Very poorly drained
Bio-physical	Soil	depth	cm	>150	50-150	30-50	<30
Bio-physical	Nutrient availability	Nutrient status	class	Very high/ high	Moderate / Low	-	-
Bio-physical	Soil class	Soil texture	type	l, scl, sil, si, cl, sicl, sic	sl	ls	c, g, sc, ac, s

Land use suitability analysis of agriculture (rubber) (continued)

Factor	Land use requirement			Factor rating			
Socio-economic	Distance	Main road	km	<1	1-5	5-10	>10
Socio-economic	Distance	Rubber factory	km	<50	50-75	75-100	>100
Socio-economic	Livelihood	Population density	n/km^2	<200	200-400	400-600	>600
Socio-economic	Livelihood	Present land use	type	agriculture	Grass, shrub	forest	Urban, water body

Note: very high(VH), high(H), moderate(M), low (L), well drained (WD), excessively drained (ED), moderately well drained (MD), somewhat poorly drained (SPD), very poorly drained (VPD), poorly drained (PD), , agriculture (AGR), grass and shrub (GRA & SHB), forest (FOR), urban (URB), water body (WTB)

Soil texture: loam(l), silty(si), sandy clay loam (scl), silty clay loam (sicl), silty loam (sil), sandy clay loam (scl), clay loam (cl), clay loam (cl), sandy loam (sl), clay (c), sandy clay (sc), silty clay (sic), sand (s), gravel soil (g)

Pair-Wise comparison matrix and weighting

Level 1: Comparison of Bio-physical vs socio-economic (By Experts' opinion)

Expert 1		Bio-physical	Socio-economic	Weight
	Bio-physical	1	7	0.875
	Socio-economic	1/7	1	0.125
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 2		Bio-physical	Socio-economic	Weight
	Bio-physical	1	9	0.9
	Socio-economic	1/9	1	0.1
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 3		Bio-physical	Socio-economic	Weight
	Bio-physical	1	5	0.833
	Socio-economic	1/5	1	0.167
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 4		Bio-physical	Socio-economic	Weight
	Bio-physical	1	9	0.9
	Socio-economic	1/9	1	0.1
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 5		Bio-physical	Socio-economic	Weight
	Bio-physical	1	5	0.833
	Socio-economic	1/5	1	0.167
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 6		Bio-physical	Socio-economic	Weight
	Bio-physical	1	7	0.875
	Socio-economic	1/7	1	0.125
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 7		Bio-physical	Socio-economic	Weight
	Bio-physical	1	7	0.875
	Socio-economic	1/7	1	0.125
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 8		Bio-physical	Socio-economic	Weight
	Bio-physical	1	5	0.833
	Socio-economic	1/5	1	0.167
	CR=CI/RI= 0/0=0 (λmax= 2)			

Level 1: Comparison of Bio-physical vs socio-economic (By Experts' opinion) (continued)

		Bio-physical	Socio-economic	Weight
Expert 9		Bio-physical	Socio-economic	Weight
	Bio-physical	1	5	0.833
	Socio-economic	1/5	1	0.167
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 10		Bio-physical	Socio-economic	Weight
	Bio-physical	1	5	0.833
	Socio-economic	1/5	1	0.167
	CR=CI/RI= 0/0=0 (λmax= 2)			

Multiple Decision Making= number of criteria=2,n= number of decision maker=10,Range= nk – n= 10*2-10=20-10=10

Factors	Bio-physical	Socio-economic	Rank	Rank/range	Weight
Bio-physical	1	10	11	11/10=1.1	0.916
Socio-economic	-	1	1	1/10=0.1	0.084
				1.2	1.000

Level2: Bio physical (Comparison between topography, soil and climate)

	Factors	Topography	Soil	Climate	Weight
Expert 1	Factors	Topography	Soil	Climate	Weight
	Topography	1	1/3	1/7	0.080
	Soil	3	1	1/5	0.189
	Climate	7	5	1	0.731
	CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.064)				
Expert 2	Factors	Topography	Soil	Climate	Weight
	Topography	1	3	5	0.624
	Soil	1/3	1	1/7	0.091
	Climate	1/5	7	1	0.283
	CR=CI/RI= 0.0354/0.58 =0.061 < 0.1 (λmax= 3.54)				
Expert 3	Factors	Topography	Soil	Climate	Weight
	Topography	1	3	1/5	0.188
	Soil	1/3	1	1/7	0.080
	Climate	5	7	1	0.730
	CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.064)				
Expert 4	Factors	Topography	Soil	Climate	Weight
	Topography	1	1/3	1/5	0.104
	Soil	3	1	1/3	0.258
	Climate	5	3	1	0.638
	CR=CI/RI= 0.019/0.58 =0.03 < 0.1 (λmax= 3.03)				

Level2: Bio physical (Comparison between topography, soil and climate)(continued)

Expert 5	Factors	Topography	Soil	Climate	Weight
	Topography	1	3	1/3	0.258
	Soil	1/3	1	1/5	0.104
	Climate	3	5	1	0.636
	CR=CI/RI= 0.019/0.58 =0.03 < 0.1 (λmax= 3.03)				
Expert 6	Factors	Topography	Soil	Climate	Weight
	Topography	1	1/3	1/7	0.080
	Soil	3	1	1/5	0.189
	Climate	7	5	1	0.731
	CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.064)				
Expert 7	Factors	Topography	Soil	Climate	Weight
	Topography	1	3	5	0.624
	Soil	1/3	1	1/7	0.091
	Climate	1/5	7	1	0.283
	CR=CI/RI= 0.0354/0.58 =0.061 < 0.1 (λmax= 3.54)				
Expert 8	Factors	Topography	Soil	Climate	Weight
	Topography	1	3	1/5	0.188
	Soil		1	1/7	0.080
	Climate			1	0.730
	CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.064)				
Expert 9	Factors	Topography	Soil	Climate	Weight
	Topography	1	1/3	1/5	0.104
	Soil	3	1	1/3	0.258
	Climate	5	3	1	0.638
	CR=CI/RI= 0.019/0.58 =0.03 < 0.1 (λmax= 3.03)				
Expert 10	Factors	Topography	Soil	Climate	Weight
	Topography	1	3	1/3	0.258
	Soil		1	1/5	0.104
	Climate			1	0.636
	CR=CI/RI= 0.019/0.58 =0.03 < 0.1 (λmax= 3.03)				

Factors	Topography	Soil	climate	Rank	Rank/range	Weight
Topography	1	6	2	9	9/20=0.45	0.27
soil	4	1	-	5	5/20=0.25	0.15
climate	8	10	1	19	19/20=0.95	0.58
					1.65	1.00

Level 2: Socio-economic (Livelihood vs Distance)

Expert 1		Livelihood	Distance	Weight
	Livelihood	1	1/3	0.25
	Distance	3	1	0.75
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 2		Livelihood	Distance	Weight
	Livelihood	1	1/5	0.167
	Distance	5	1	0.833
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 3		Livelihood	Distance	Weight
	Livelihood	1	1/9	0.1
	Distance	9	1	0.9
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 4		Livelihood	Distance	Weight
	Livelihood	1	3	0.75
	Distance	1/3	1	0.25
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 5		Livelihood	Distance	Weight
	Livelihood	1	5	0.833
	Distance	1/5	1	0.167
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 6		Livelihood	Distance	Weight
	Livelihood	1	1/3	0.25
	Distance	3	1	0.75
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 7		Livelihood	Distance	Weight
	Livelihood	1	1/5	0.167
	Distance	5	1	0.833
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 8		Livelihood	Distance	Weight
	Livelihood	1	1/9	0.1
	Distance	9	1	0.9
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 9		Livelihood	Distance	Weight
	Livelihood	1	3	0.75
	Distance	1/3	1	0.25
	CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 10		Livelihood	Distance	Weight
	Livelihood	1	5	0.833
	Distance	1/5	1	0.167
	CR=CI/RI= 0/0=0 (λmax= 2)			

Factors	livelihood	Distance	Rank	Rank/range	Weight
livelihood	1	4	5	5/10=0.5	0.416
Distance	6	1	7	7/10=0.7	0.584
				1.2	1.00

Level 3: Biophysical: Topography (Slope vs Elevation)

Level 3: Biophysical: Topography (Slope vs Elevation)					
Expert 1		Slope	Elevation		Weight
	Slope	1	7		0.875
	Elevation	1/7	1		0.125
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 2		Slope	Elevation		Weight
	Slope	1	9		0.9
	Elevation	1/9	1		0.1
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 3		Slope	Elevation		Weight
	Slope	1	5		0.833
	Elevation	1/5	1		0.167
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 4		Slope	Elevation		Weight
	Slope	1	9		0.9
	Elevation	1/9	1		0.1
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 5		Slope	Elevation		Weight
	Slope	1	1/5		0.167
	Elevation	5	1		0.833
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 6		Slope	Elevation		Weight
	Slope	1	7		0.875
	Elevation	1/7	1		0.125
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 7		Slope	Elevation		Weight
	Slope	1	9		0.9
	Elevation	1/9	1		0.1
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 8		Slope	Elevation		Weight
	Slope	1	5		0.833
	Elevation	1/5	1		0.167
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 9		Slope	Elevation		Weight
	Slope	1	9		0.9
	Elevation	1/9	1		0.1
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 10		Slope	Elevation		Weight
	Slope	1	1/5		0.167
	Elevation	5	1		0.833
	CR=CI/RI= 0/0=0 (λmax= 2)				
Factors	Slope	Elevation	Rank	Rank/range	Weight
Slope	1	8	9	9/10=0.9	0.75
Elevation	2	1	3	3/10=0.3	0.25
				1.2	1.000

Level 3: Biophysical: Climate (Rainfall vs Temperature)

Expert 1		Rainfall	Temp		Weight
	Rainfall	1	7		0.875
	Temp	1/7	1		0.125
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 2		Rainfall	Temp		Weight
	Rainfall	1	9		0.9
	Temp	1/9	1		0.1
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 3		Rainfall	Temp		Weight
	Rainfall	1	5		0.833
	Temp	1/5	1		0.167
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 4		Rainfall	Temp		Weight
	Rainfall	1	1/5		0.167
	Temp	5	1		0.833
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 5		Rainfall	Temp		Weight
	Rainfall	1	1/5		0.167
	Temp	5	1		0.833
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 6		Rainfall	Temp		Weight
	Rainfall	1	7		0.875
	Temp	1/7	1		0.125
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 7		Rainfall	Temp		Weight
	Rainfall	1	9		0.9
	Temp	1/9	1		0.1
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 8		Rainfall	Temp		Weight
	Rainfall	1	5		0.833
	Temp	1/5	1		0.167
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 9		Rainfall	Temp		Weight
	Rainfall	1	1/5		0.167
	Temp	5	1		0.833
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 10		Rainfall	Temp		Weight
	Rainfall	1	1/5		0.167
	Temp	5	1		0.833
	CR=CI/RI= 0/0=0 (λmax= 2)				
Factors	Rainfall	Temp	Rank	Rank/range	Weight
Rainfall	1	6	7	7/10=0.7	o.58
Temp	4	1	5	5/10=0.5	0.42
				1.2	1.00

Level 3: Bio-physical: Soil (Drainage, pH, Depth, Nutrient, Texture)

Expert 1	Factor	Drainage	pH	Depth	Nutrient	Texture	Weight
	Drainage	1	1/3	1/5	1/3	1/5	0.052
	pH	3	1	3	3	1/3	0.238
	Depth	5	1/3	1	3	1/3	0.166
	Nutrient	3	1/3	1/3	1	1/7	0.080
	Texture	5	3	3	7	1	0.461

CR=CI/RI=0.11/1.12=0.098 <0.1 (λmax= 5.42)

Expert 2	Factor	Drainage	pH	Depth	Nutrient	Texture	Weight
	Drainage	1	3	1/3	3	1/5	0.121
	pH	1/3	1	1/3	3	1/3	0.091
	Depth	3	3	1	7	1/3	0.292
	Nutrient	1/3	1/3	1/7	1	1/7	0.039
	Texture	5	3	3	7	1	0.455

CR=CI/RI=0.11/1.12=0.098 <0.1 (λmax= 5.42)

Expert 3	Factor	Drainage	pH	Depth	Nutrient	Texture	Weight
	Drainage	1	1/3	1/3	5	1/3	0.104
	pH	3	1	1/3	1/3	1/3	0.164
	Depth	3	3	1	7	3	0.424
	Nutrient	1/5	1/5	1/7	1	1/7	0.034
	Texture	3	3	1/3	7	1	0.271

CR=CI/RI=0.09/1.12=0.08 <0.1 (λmax= 5.39)

Expert 4	Factor	Drainage	pH	Depth	Nutrient	Texture	Weight
	Drainage	1	1/3	1/3	5	1/3	0.104
	pH	3	1	1/3	1/3	1/3	0.164
	Depth	3	3	1	7	3	0.424
	Nutrient	1/5	1/5	1/7	1	1/7	0.034
	Texture	3	3	1/3	7	1	0.271

CR=CI/RI=0.09/1.12=0.08 <0.1 (λmax= 5.39)

Expert 5	Factor	Drainage	pH	Depth	Nutrient	Texture	Weight
	Drainage	1	3	3	5	1/3	0.231
	pH	1/3	1	3	5	1/5	0.137
	Depth	1/3	1/5	1	3	1/7	0.072
	Nutrient	1/5	3	1/3	1	1/9	0.036
	Texture	3	5	7	9	1	0.521

CR=CI/RI=0.06/1.12=0.05 <0.1 (λmax= 5.24)

Expert 6	Factor	Drainage	pH	Depth	Nutrient	Texture	Weight
	Drainage	1	1/3	1/5	1/3	1/5	0.052
	pH	3	1	3	3	1/3	0.238
	Depth	5	1/3	1	3	1/3	0.166
	Nutrient	3	1/3	1/3	1	1/7	0.080
	Texture	5	3	3	7	1	0.461

CR=CI/RI=0.106/1.12=0.09 <0.1 (λmax= 5.42)

Level 3: Bio-physical: Soil (Drainage, pH, Depth, Nutrient, Texture) (continued)

Expert 7	Factor	Drainage	pH	Depth	Nutrient	Texture	Weight
	Drainage	1	3	1/3	3	1/5	0.121
	pH	1/3	1	1/3	3	1/3	0.091
	Depth	3	3	1	7	1/3	0.292
	Nutrient	1/3	1/3	1/7	1	1/7	0.039
	Texture	5	3	3	7	1	0.455

CR=CI/RI=0.11/1.12=0.098 <0.1 (λmax= 5.42)

Expert 8	Factor	Drainage	pH	Depth	Nutrient	Texture	Weight
	Drainage	1	1/3	1/3	5	1/3	0.104
	pH	3	1	1/3	1/3	1/3	0.164
	Depth	3	3	1	7	3	0.424
	Nutrient	1/5	1/5	1/7	1	1/7	0.034
	Texture	3	3	1/3	7	1	0.271

CR=CI/RI=0.09/1.12=0.08 <0.1 (λmax= 5.39)

Expert 9	Factor	Drainage	pH	Depth	Nutrient	Texture	Weight
	Drainage	1	1/3	1/3	5	1/3	0.104
	pH	3	1	1/3	1/3	1/3	0.164
	Depth	3	3	1	7	3	0.424
	Nutrient	1/5	1/5	1/7	1	1/7	0.034
	Texture	3	3	1/3	7	1	0.271

CR=CI/RI=0.09/1.12=0.08 <0.1 (λmax= 5.39)

Expert10	Factor	Drainage	pH	Depth	Nutrient	Texture	Weight
	Drainage	1	3	3	5	1/3	0.231
	pH	1/3	1	3	5	1/5	0.137
	Depth	1/3	1/5	1	3	1/7	0.072
	Nutrient	1/5	3	1/3	1	1/9	0.036
	Texture	3	5	7	9	1	0.521

CR=CI/RI=0.06/1.12=0.05 <0.1 (λmax= 5.24)

Factors	Drainage	pH	Depth	Nutrient	Texture	Rank	Rank/range	Weight
Drainage	1	4	2	8	-	15	15/40=0.375	0.148
pH	6	1	4	6	-	17	17/40=0.425	0.168
Depth	8	6	1	10	4	29	29/40=0.725	0.287
Nutrient	2	-	-	1	-	3	3/40=0.075	0.029
Texture	10	10	6	10	1	37	37/40=0.925	0.366

Level3: Socio-economic: Livelihood (Population density vs Available land use)

Expert 1		Population	Land use		Weight
	Population	1	1/3		0.25
	Land use	3	1		0.75
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 2		Population	Land use		Weight
	Population	1	1/5		0.167
	Land use	5	1		0.833
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 3		Population	Land use		Weight
	Population	1	1/9		0.1
	Land use	9	1		0.9
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 4		Population	Land use		Weight
	Population	1	3		0.75
	Land use	1/3	1		0.25
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 5		Population	Land use		Weight
	Population	1	5		0.833
	Land use	1/5	1		0.167
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 6		Population	Land use		Weight
	Population	1	1/3		0.25
	Land use	3	1		0.75
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 7		Population	Land use		Weight
	Population	1	1/5		0.167
	Land use	5	1		0.833
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 8		Population	Land use		Weight
	Population	1	1/9		0.1
	Land use	9	1		0.9
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 9		Population	Land use		Weight
	Population	1	3		0.75
	Land use	1/3	1		0.25
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 10		Population	Land use		Weight
	Population	1	5		0.833
	Land use	1/5	1		0.167
	CR=CI/RI= 0/0=0 (λmax= 2)				
Factors	Population	Land use	Rank	Rank/range	Weight
Population	1	4	5	5/10=0.5	0.416
Land use	6	1	7	7/10=0.7	0.584
				1.2	1.00

Level3: Socio-economic: Distance (Distance from main road vs distance from factory)

Expert 1		Road	Factory		Weight
	Road	1	7		0.875
	Factory	1/7	1		0.125
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 2		Road	Factory		Weight
	Road	1	9		0.9
	Factory	1/9	1		0.1
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 3		Road	Factory		Weight
	Road	1	5		0.833
	Factory	1/5	1		0.167
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 4		Road	Factory		Weight
	Road	1	1/5		0.167
	Factory	5	1		0.833
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 5		Road	Factory		Weight
	Road	1	1/5		0.167
	Factory	5	1		0.833
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 6		Road	Factory		Weight
	Road	1	7		0.875
	Factory	1/7	1		0.125
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 7		Road	Factory		Weight
	Road	1	9		0.9
	Factory	1/9	1		0.1
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 8		Road	Factory		Weight
	Road	1	5		0.833
	Factory	1/5	1		0.167
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 9		Road	Factory		Weight
	Road	1	1/5		0.167
	Factory	5	1		0.833
	CR=CI/RI= 0/0=0 (λmax= 2)				
Expert 10		Road	Factory		Weight
	Road	1	1/5		0.167
	Factory	5	1		0.833
	CR=CI/RI= 0/0=0 (λmax= 2)				
Factors	Road	Factory	Rank	Rank/range	Weight
Road	1	6	7	7/10=0.7	o.58
Factory	4	1	5	5/10=0.5	0.42
				1.2	1.00

APPENDIX F

Land use suitability analysis of forest

Factor	Land use requirement			Factor rating			
	Land quality	Factor	Unit	S1	S2	S3	N
Bio-physical	Climate	Mean temp	^{0}C	24-28	28-30	30-32	>32,<24
Bio-physical	Climate	Annual rainfall	Mm	>2000	1500-2000	1000-1500	<1000
Bio-physical	Topography	Slope	Class	<8	8-25	25-45	>45
Bio-physical	Elevation	Altitude	M	<200	200-400	400-1000	>1000
Bio-physical	Soil	pH value	pH	5-6	6-7, 4-5	7-8, 3-4	<3, >8
Bio-physical	Soil	drainage	Class	Well drained/ Excessively drained	Moderately well drained	Somewhat poorly drained	Poorly drained Very poorly drained
Bio-physical	Soil	depth	Cm	>150	100-150	50-100	<50
Bio-physical	Nutrient availability	Nutrient status	Class	Very high/ high	Moderate/ Low	-	-
Bio-physical	Soil class	Soil texture	Type	l, scl, sl	Ls, sil, sc, cl, sicl	Si , sic, sc,	c, g, ac, s
Socio-economic	Distance	Main road	Km	>5	4-5	3-4	<3
Socio-economic	Distance	River	Km	<1	1-2	2-3	>3
Socio-economic	Livelihood	Population density	n/km 2	<100	100-200	200-300	>300
Socio-economic	Livelihood	Present land use	Type	forest	Grass, shrub	agriculture	Urban, water body

Pair-Wise comparison matrix and weighting

Level 1: Comparison of Bio-physical vs socio-economic (By Experts' opinion)

Expert 1	Bio-physical	Socio-economic	Weight
Bio-physical	1	7	0.875
Socio-economic	1/7	1	0.125
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert2	Bio-physical	Socio-economic	Weight
Bio-physical	1	9	0.9
Socio-economic	1/9	1	0.1
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert3	Bio-physical	Socio-economic	Weight
Bio-physical	1	5	0.833
Socio-economic	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert4	Bio-physical	Socio-economic	Weight
Bio-physical	1	9	0.9
Socio-economic	1/9	1	0.1
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert5	Bio-physical	Socio-economic	Weight
Bio-physical	1	5	0.833
Socio-economic	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert6	Bio-physical	Socio-economic	Weight
Bio-physical	1	7	0.875
Socio-economic	1/7	1	0.125
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert7	Bio-physical	Socio-economic	Weight
Bio-physical	1	7	0.875
Socio-economic	1/7	1	0.125
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 8	Bio-physical	Socio-economic	Weight
Bio-physical	1	5	0.833
Socio-economic	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			

Level 1: Comparison of Bio-physical vs socio-economic (By Experts' opinion) (continued)

Expert 9	Bio-physical	Socio-economic	Weight
Bio-physical	1	1/3	0.25
Socio-economic	3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 10	Bio-physical	Socio-economic	Weight
Bio-physical	1	5	0.167
Socio-economic	1/5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Factors	Bio-physical	Socio-economic	Rank	Rank/range	Weight
Bio-physical	1	8	9	9/10=0.9	0.75
Socio-economic	2	1	3	3/10=0.3	0.25
				1.2	1.000

Level2: Bio physical (Comparison between topography, soil and climate)

Expert 1	Topography	Climate	Soil	Weight
Topography	1	3	7	0.64918
Climate	1/3	1	5	0.27895
Soil	0.14287	0.3333	1	0.071924
CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.064)				
Expert 2	Topography	Climate	Soil	Weight
Topography	1	3	5	0.636986
Climate	1/3	1	3	0.258285
Soil	1/5	1/3	1	0.104729
CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.038)				
Expert 3	Topography	Climate	Soil	Weight
Topography	1	5	7	0.730645
Climate	1/5	1	3	0.188394
Soil	1/7	1/3	1	0.0809612
CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.064)				
Expert 4	Topography	Climate	Soil	Weight
Topography	1	1/5	3	0.188394
Climate	5	1	7	0.730645
Soil	1/3	1/7	1	0.0809612
CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.038)				

Level2: Bio physical (Comparison between topography, soil and climate) (continued)

Expert 5	Topography	Climate	Soil	Weight
Topography	1	5	3	0.636986
Climate	1/5	1	1/3	0.104729
Soil	1/3	3	1	0.258285

CR=CI/RI= 0.0192/0.58=0.032 < 0.1 (λmax= 3.038)

Expert 6	Topography	Climate	Soil	Weight
Topography	1	1/3	3	0.258285
Climate	3	1	5	0.636986
Soil	1/3	1/5	1	0.104729

CR=CI/RI= 0.019/0.58 =0.032 < 0.1 (λmax= 3.038)

Expert 7	Topography	Climate	Soil	Weight
Topography	1	1/3	5	0.278955
Climate	3	1	7	0.649118
Soil	1/5	1/7	1	0.0719274

CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.064)

Expert 8	Topography	Climate	Soil	Weight
Topography	1	1/3	7	0.289744
Climate	3	1	9	0.655355
Soil	1/7	1/9	1	0.0549004

CR=CI/RI= 0.0401/0.58 =0.06 < 0.1 (λmax= 3.083)

Expert 9	Topography	Climate	Soil	Weight
Topography	1	1/3	1/7	0.08464
Climate	3	1	1/5	0.70059
Soil	7	5	1	0.21476

CR=CI/RI= 0.056/0.58 =0.09 < 0.1 (λmax= 4.1213)

Expert 10	Topography	Climate	Soil	Weight
Topography	1	1/3	1/7	0.0809612
Climate	3	1	1/5	0.188394
Soil	7	5	1	0.730645

CR=CI/RI= 0.0302/0.58 =0.055 < 0.1 (λmax= 3.083)

Factors	Topography	climate	soil	Rank	Rank/range	Weight
Topography	1	4	8	13	13/20= 0.65	0.3940
climate	6	1	8	15	15/20= 0.75	0.4545
soil	2	2	1	5	5/20= 0.25	0.1515
					1.65	1.0000

Level2: Socio-economic (Livelihood vs Distance)

Expert 1	Livelihood	Distance	Weight		
Livelihood	1	5	0.833		
Distance	1/5	1	0.167		
CR=CI/RI= 0/0=0 (λmax= 2)					
Expert 2	Livelihood	Distance	Weight		
Livelihood	1	1/5	0.167		
Distance	5	1	0.833		
CR=CI/RI= 0/0=0 (λmax= 2)					
Expert 3	Livelihood	Distance	Weight		
Livelihood	1	1/9	0.1		
Distance	9	1	0.9		
CR=CI/RI= 0/0=0 (λmax= 2)					
Expert 4	Livelihood	Distance	Weight		
Livelihood	1	3	0.75		
Distance	1/3	1	0.25		
CR=CI/RI= 0/0=0 (λmax= 2)					
Expert 5	Livelihood	Distance	Weight		
Livelihood	1	5	0.833		
Distance	1/5	1	0.167		
CR=CI/RI= 0/0=0 (λmax= 2)					
Expert 6	Livelihood	Distance	Weight		
Livelihood	1	5	0.833		
Distance	1/5	1	0.167		
CR=CI/RI= 0/0=0 (λmax= 2)					
Expert 7	Livelihood	Distance	Weight		
Livelihood	1	1/5	0.167		
Distance	5	1	0.833		
CR=CI/RI= 0/0=0 (λmax= 2)					
Expert 8	Livelihood	Distance	Weight		
Livelihood	1	1/9	0.1		
Distance	9	1	0.9		
CR=CI/RI= 0/0=0 (λmax= 2)					
Expert 9	Livelihood	Distance	Weight		
Livelihood	1	3	0.75		
Distance	1/3	1	0.25		
CR=CI/RI= 0/0=0 (λmax= 2)					
Expert 10	Livelihood	Market	Weight		
Livelihood	1	5	0.833		
Market	1/5	1	0.167		
CR=CI/RI= 0/0=0 (λmax= 2)					
Factors	livelihood	Distance	Rank	Rank/range	Weight
livelihood	1	6	7	7/10=0.7	0.5834
Distance	4	1	5	5/10=0.5	0.4166
				1.2	1.00

Level 3: Biophysical: Topography (Slope vs Elevation)

Expert1	Slope	Elevation	Weight
Slope	1	7	0.875
Elevation	1/7	1	0.125

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 2	Slope	Elevation	Weight
Slope	1	9	0.9
Elevation	1/9	1	0.1

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 3	Slope	Elevation	Weight
Slope	1	5	0.833
Elevation	1/5	1	0.167

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 4	Slope	Elevation	Weight
Slope	1	9	0.9
Elevation	1/9	1	0.1

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 5	Slope	Elevation	Weight
Slope	1	1/5	0.167
Elevation	5	1	0.833

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 6	Slope	Elevation	Weight
Slope	1	7	0.875
Elevation	1/7	1	0.125

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 7	Slope	Elevation	Weight
Slope	1	9	0.9
Elevation	1/9	1	0.1

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 8	Slope	Elevation	Weight
Slope	1	5	0.833
Elevation	1/5	1	0.167

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 9	Slope	Elevation	Weight
Slope	1	9	0.9
Elevation	1/9	1	0.1

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 10	Slope	Elevation	Weight
Slope	1	1/5	0.167
Elevation	5	1	0.833

CR=CI/RI= 0/0=0 (λmax= 2)

Factors	Slope	Elevation	Rank	Rank/range	Weight
Slope	1	8	9	9/10=0.9	0.75
Elevation	2	1	3	3/10=0.3	0.25
				1.2	1.000

Level 3: Biophysical: Climate (Rainfall vs Temperature)

Expert 1	Rainfall	Temp	Weight
Rainfall	1	7	0.875
Temp	1/7	1	0.125

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 2	Rainfall	Temp	Weight
Rainfall	1	9	0.9
Temp	1/9	1	0.1

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 3	Rainfall	Temp	Weight
Rainfall	1	5	0.833
Temp	1/5	1	0.167

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 4	Rainfall	Temp	Weight
Rainfall	1	1/5	0.167
Temp	5	1	0.833

CR=CI/RI= 0/0=0 (λmax= 2)

Expert 5	Rainfall	Temp	Weight
Rainfall	1	1/5	0.167
Temp	5	1	0.833

CR=CI/RI= 0/0=0 (λmax= 2)

Expert6	Rainfall	Temp	Weight
Rainfall	1	7	0.875
Temp	1/7	1	0.125

CR=CI/RI= 0/0=0 (λmax= 2)

Expert7	Rainfall	Temp	Weight
Rainfall	1	9	0.9
Temp	1/9	1	0.1

CR=CI/RI= 0/0=0 (λmax= 2)

Expert8	Rainfall	Temp	Weight
Rainfall	1	5	0.833
Temp	1/5	1	0.167

CR=CI/RI= 0/0=0 (λmax= 2)

Expert9	Rainfall	Temp	Weight
Rainfall	1	1/5	0.167
Temp	5	1	0.833

CR=CI/RI= 0/0=0 (λmax= 2)

Expert10	Rainfall	Temp	Weight
Rainfall	1	1/5	0.167
Temp	5	1	0.833

CR=CI/RI= 0/0=0 (λmax= 2)

Factors	Rainfall	Temp	Rank	Rank/range	Weight
Rainfall	1	6	7	7/10=0.7	0.58
Temp	4	1	5	5/10=0.5	0.42
				1.2	1.00

Level 3: Bio-physical: Soil (Drainage, pH, Depth, Nutrient, Texture)

Expert1	Drainage	pH	Depth	Nutrient	Texture	Weight
Drainage	1	1/3	1/5	1/3	1/5	0.052
pH	3	1	3	3	1/3	0.238
Depth	5	1/3	1	3	1/3	0.166
Nutrient	3	1/3	1/3	1	1/7	0.080
Texture	5	3	3	7	1	0.461

CR=CI/RI=0.106/1.12=0.09 <0.1 (λmax= 5.42)

Expert2	Drainage	pH	Depth	Nutrient	Texture	Weight
Drainage	1	3	1/3	3	1/5	0.121
pH	1/3	1	1/3	3	1/3	0.091
Depth	3	3	1	7	1/3	0.292
Nutrient	1/3	1/3	1/7	1	1/7	0.039
Texture	5	3	3	7	1	0.455

CR=CI/RI=0.11/1.12=0.098 <0.1 (λmax= 5.42)

Expert3	Drainage	pH	Depth	Nutrient	Texture	Weight
Drainage	1	9	3	7	5	0.509348
pH	1/9	1	1/7	1/3	1/7	0.0312624
Depth	1/3	7	1	5	3	0.259448
Nutrient	1/7	3	1/5	1	1/3	0.0617217
Texture	1/5	7	1/3	3	1	0.13822

CR=CI/RI=0.07139/1.12=0.06 <0.1 (λmax= 5.28558)

Expert4	Drainage	pH	Depth	Nutrient	Texture	Weight
Drainage	1	7	5	9	3	0.51478
pH	1/7	1	1/3	3	1/5	0.067303
Depth	1/5	3	1	5	1/3	0.136494
Nutrient	1/9	1/3	1/5	1	1/3	0.042610
Texture	1/3	5	3	3	1	0.23881

CR=CI/RI=0.0944/1.12=0.08 <0.1 (λmax= 5.37765)

Expert5	Drainage	pH	Depth	Nutrient	Texture	Weight
Drainage	1	5	3	7	1/3	0.268121
pH	1/5	1	1/3	3	1/7	0.067100
Depth	1/3	3	1	3	1/5	0.11994
Nutrient	1/7	1/3	1/3	1	1/9	0.04039
Texture	3	7	5	7	1	0.50444

CR=CI/RI=0.0687/1.12=0.053 <0.1 (λmax= 5.275)

Expert6	Drainage	pH	Depth	Nutrient	Texture	Weight
Drainage	1	5	1/3	7	3	0.263843
pH	1/5	1	1/7	3	1/3	0.065597
Depth	3	7	1	9	5	0.515339
Nutrient	1/7	1/3	1/9	1	1/3	0.037016
Texture	1/3	3	1/5	3	1	0.118204

CR=CI/RI=0.055/1.12=0.0491 <0.1 (λmax= 5.22)

Level 3: Bio-physical: Soil (Drainage, pH, Depth, Nutrient, Texture) (continued)

Expert7	Drainage	pH	Depth	Nutrient	Texture	Weight
Drainage	1	3	1/3	3	1/5	0.121
pH	1/3	1	1/3	3	1/3	0.091
Depth	3	3	1	7	1/3	0.292
Nutrient	1/3	1/3	1/7	1	1/7	0.039
Texture	5	3	3	7	1	0.455

CR=CI/RI=0.11/1.12=0.098 <0.1 (λmax= 5.42)

Expert8	Drainage	pH	Depth	Nutrient	Texture	Weight
Drainage	1	1/3	1/3	5	1/3	0.104
pH	3	1	1/3	1/3	1/3	0.164
Depth	3	3	1	7	3	0.424
Nutrient	1/5	1/5	1/7	1	1/7	0.034
Texture	3	3	1/3	7	1	0.271

CR=CI/RI=0.09/1.12=0.08 <0.1 (λmax= 5.39)

Expert9	Drainage	pH	Depth	Nutrient	Texture	Weight
Drainage	1	1/3	1/3	5	1/3	0.104
pH	3	1	1/3	1/3	1/3	0.164
Depth	3	3	1	7	3	0.424
Nutrient	1/5	1/5	1/7	1	1/7	0.034
Texture	3	3	1/3	7	1	0.271

CR=CI/RI=0.09/1.12=0.08 <0.1 (λmax= 5.39)

Expert10	Drainage	pH	Depth	Nutrient	Texture	Weight
Drainage	1	3	3	5	1/3	0.231
pH	1/3	1	3	5	1/5	0.137
Depth	1/3	1/5	1	3	1/7	0.072
Nutrient	1/5	3	1/3	1	1/9	0.036
Texture	3	5	7	9	1	0.521

CR=CI/RI=0.06/1.12=0.05 <0.1 (λmax= 5.24)

Factors	Drainage	pH	Depth	Nutrient	Texture	Rank	Rank/range	Weight
Drainage	1	9	5	10	4	29	29/40= 0.725	0.2815
pH	1	1	1	8	-	11	11/40= 0.275	0.1067
Depth	5	9	1	9	4	28	28/40= 0.700	0.2718
Nutrient	-	2	1	1	1	5	5/40= 0.125	0.0488
Texture	6	9	5	9	1	30	30/40= 0.750	0.2912
						103	2.575	1.00

Level3: Socio-economic: Livelihood (Population density vs Available land use)

Expert1	Population	Land use	Weight
Population	1	1/3	0.25
Land use	3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert2	Population	Land use	Weight
Population	1	1/5	0.167
Land use	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert3	Population	Land use	Weight
Population	1	1/9	0.1
Land use	9	1	0.9
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert4	Population	Land use	Weight
Population	1	3	0.75
Land use	1/3	1	0.25
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert5	Population	Land use	Weight
Population	1	5	0.833
Land use	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert6	Population	Land use	Weight
Population	1	1/3	0.25
Land use	3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert7	Population	Land use	Weight
Population	1	1/5	0.167
Land use	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert8	Population	Land use	Weight
Population	1	1/9	0.1
Land use	9	1	0.9
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert9	Population	Land use	Weight
Population	1	3	0.75
Land use	1/3	1	0.25
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert10	Population	Land use	Weight
Population	1	5	0.833
Land use	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			

Factors	Population	Land use	Rank	Rank/range	Weight
Population	1	4	5	5/10=0.5	0.416
Land use	6	1	7	7/10=0.7	0.584
				1.2	1.00

Level3: Socio-economic: Distance (Distance from main road vs distance from river)

Expert1	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert2	Road	River	Weight
Road	1	9	0.9
River	1/9	1	0.1
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert3	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert4	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert5	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 6	Road	River	Weight
Road	1	7	0.875
River	1/7	1	0.125
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 7	Road	River	Weight
Road	1	9	0.9
River	1/9	1	0.1
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 8	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 9	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 10	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Factors	Road	River	Rank	Rank/range	Weight
Road	1	3	4	4/10=0.4	0.34
River	7	1	8	5/10=0.8	0.66
				1.2	1.00

APPENDIX G

Land use suitability analysis of urban

Factor	Land use requirement			Factor rating			
	Land quality	Factor	Unit	S1	S2	S3	N
Bio-physical	Climate	Mean temp	^{0}C	20-25	15-20, 25-30	10-15, 30-35	<10, >35
Bio-physical	Climate	Annual rainfall	mm	>200	150-200	100-150	<100
Bio-physical	Topography	Slope	class	<5	5-10	10-15	>15
Bio-physical	Elevation	Altitude	m	0-100	100-1000	1000-2000	>2000
Bio-physical	Soil	drainage	class	Well drained/ Excessively drained	Moderately well drained	Somewhat poorly drained	Poorly drained Very poor drained
Bio-physical	Soil	depth	cm	>150	50-150	30-50	<30
Bio-physical	Soil class	Soil texture	type	sandy	loamy	clayey	Rocky/sto e
Socio-economic	Distance	Main road	km	<1	1-5	5-10	>10
Socio-economic	Distance	River	km	>5	4-5	3-4	<3
Socio-economic	Livelihood	Population density	n/km^2	1000-2000	800-1000, 2000-2500	500-800, 2500-3000	>3000, <500
Socio-economic	Livelihood	Present land use	type	urban	Grass, shrub	agriculture	Forest, water bod

Pair-Wise comparison matrix and weighting

Level 1: Comparison of Bio-physical vs socio-economic (By Experts' opinion)

Expert 1	Bio-physical	Socio-economic	Weight
Bio-physical	1	7	0.875
Socio-economic	1/7	1	0.125
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert2	Bio-physical	Socio-economic	Weight
Bio-physical	1	1/3	0.25
Socio-economic	3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert3	Bio-physical	Socio-economic	Weight
Bio-physical	1	5	0.833
Socio-economic	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert4	Bio-physical	Socio-economic	Weight
Bio-physical	1	9	0.9
Socio-economic	1/9	1	0.1
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert5	Bio-physical	Socio-economic	Weight
Bio-physical	1	5	0.833
Socio-economic	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert6	Bio-physical	Socio-economic	Weight
Bio-physical	1	1/3	0.25
Socio-economic	3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert7	Bio-physical	Socio-economic	Weight
Bio-physical	1	7	0.875
Socio-economic	1/7	1	0.125
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 8	Bio-physical	Socio-economic	Weight
Bio-physical	1	5	0.833
Socio-economic	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 9	Bio-physical	Socio-economic	Weight
Bio-physical	1	1/3	0.25
Socio-economic	3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 10	Bio-physical	Socio-economic	Weight
Bio-physical	1	1/5	0.833
Socio-economic	5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			

Factors	Bio-physical	Socio-economic	Rank	Rank/range	Weight
Bio-physical	1	6	7	7/10=0.7	0.5833
Socio-economic	4	1	5	5/10=0.5	0.4167
				1.2	1.000

Level2: Bio physical (Comparison between topography, soil and climate)

Expert 1	Topography	Climate	Soil	Weight
Topography	1	3	7	0.64918
Climate	1/3	1	5	0.27895
Soil	1/7	1/5	1	0.071924
CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.064)				
Expert 2	Topography	Climate	Soil	Weight
Topography	1	3	5	0.636986
Climate	1/3	1	3	0.258285
Soil	1/5	1/3	1	0.104729
CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.038)				
Expert 3	Topography	Climate	Soil	Weight
Topography	1	5	7	0.730645
Climate	1/5	1	3	0.188394
Soil	1/7	1/3	1	0.0809612
CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.064)				
Expert 4	Topography	Climate	Soil	Weight
Topography	1	1/5	3	0.188394
Climate	5	1	7	0.730645
Soil	1/3	1/7	1	0.0809612
CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.038)				
Expert 5	Topography	Climate	Soil	Weight
Topography	1	5	3	0.636986
Climate	1/5	1	1/3	0.104729
Soil	1/3	3	1	0.258285
CR=CI/RI= 0.0192/0.58=0.032 < 0.1 (λmax= 3.038)				
Expert 6	Topography	Climate	Soil	Weight
Topography	1	3	7	0.64918
Climate	1/3	1	5	0.27895
Soil	0.14287	0.3333	1	0.071924
CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.064)				
Expert 7	Topography	Climate	Soil	Weight
Topography	1	1/3	5	0.278955
Climate	3	1	7	0.649118
Soil	1/5	1/7	1	0.0719274
CR=CI/RI= 0.032/0.58 =0.055 < 0.1 (λmax= 3.064)				
Expert 8	Topography	Climate	Soil	Weight
Topography	1	1/3	7	0.289744
Climate	3	1	9	0.655355
Soil	1/7	1/9	1	0.0549004
CR=CI/RI= 0.0401/0.58 =0.06 < 0.1 (λmax= 3.083)				

Level2: Bio physical (Comparison between topography, soil and climate)(continued)

Expert 9	Topography	Climate	Soil	Weight
Topography	1	1/3	1/7	0.08464
Climate	3	1	1/5	0.70059
Soil	7	5	1	0.21476
CR=CI/RI= 0.056/0.58 =0.09 < 0.1 (λmax= 4.1213)				

Expert 10	Topography	Climate	Soil	Weight
Topography	1	5	3	0.636986
Climate	1/5	1	1/3	0.104729
Soil	1/3	3	1	0.258285
CR=CI/RI= 0.0192/0.58=0.032 < 0.1 (λmax= 3.038)				

Factors	Topography	Climate	soil	Rank	Rank/range	Weight
Topography	1	5	9	15	15/20= 0.75	0.4545
climate	5	1	8	14	14/20= 0.70	0.4242
soil	1	2	1	4	4/20= 0.20	0.1213
					1.65	1.0000

Level2: Socio-economic (Livelihood vs Distance)

Livelihood	Distance	Weight
1	5	0.833
1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)		

Livelihood	Distance	Weight
1	3	0.75
1/3	1	0.25
CR=CI/RI= 0/0=0 (λmax= 2)		

Livelihood	Distance	Weight
1	1/3	0.25
3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)		

Livelihood	Distance	Weight
1	3	0.75
1/3	1	0.25
CR=CI/RI= 0/0=0 (λmax= 2)		

Livelihood	Distance	Weight
1	5	0.833
1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)		

Livelihood	Distance	Weight
1	5	0.833
1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)		

Level2: Socio-economic (Livelihood vs Distance) (continued)

Livelihood	Distance	Weight
1	5	0.833
1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)		

Livelihood	Distance	Weight
1	1/3	0.25
3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)		

Livelihood	Distance	Weight
1	3	0.75
1/3	1	0.25
CR=CI/RI= 0/0=0 (λmax= 2)		

Livelihood	Market	Weight
1	1/3	0.25
3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)		

Factors	livelihood	Distance	Rank	Rank/range	Weight
livelihood	1	7	8	8/10=0.8	0.667
Distance	3	1	4	4/10=0.4	0.333
				1.2	1.00

Level 3: Biophysical: Topography (Slope vs Elevation)

Expert1	Slope	Elevation	Weight
Slope	1	7	0.875
Elevation	1/7	1	0.125
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert 2	Slope	Elevation	Weight
Slope	1	9	0.9
Elevation	1/9	1	0.1
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert 3	Slope	Elevation	Weight
Slope	1	5	0.833
Elevation	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert 4	Slope	Elevation	Weight
Slope	1	1/3	0.25
Elevation	3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)			

Level 3: Biophysical: Topography (Slope vs Elevation) (continued)

Expert 5	Slope	Elevation	Weight
Slope	1	1/5	0.167
Elevation	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 6	Slope	Elevation	Weight
Slope	1	7	0.875
Elevation	1/7	1	0.125
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 7	Slope	Elevation	Weight
Slope	1	9	0.9
Elevation	1/9	1	0.1
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 8	Slope	Elevation	Weight
Slope	1	5	0.833
Elevation	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 9	Slope	Elevation	Weight
Slope	1	1/3	0.25
Elevation	3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 10	Slope	Elevation	Weight
Slope	1	1/5	0.167
Elevation	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Factors	Slope	Elevation	Rank	Rank/range	Weight
Slope	1	6	7	7/10=0.7	0.5833
Elevation	4	1	5	5/10=0.5	0.4167
				1.2	1.000

Level 3: Biophysical: Climate (Rainfall vs Temperature)

Expert 1	Rainfall	Temp	Weight
Rainfall	1	7	0.875
Temp	1/7	1	0.125
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert 2	Rainfall	Temp	Weight
Rainfall	1	3	0.75
Temp	1/3	1	0.25
CR=CI/RI= 0/0=0 (λmax= 2)			

Level 3: Biophysical: Climate (Rainfall vs Temperature)

Expert 3	Rainfall	Temp	Weight
Rainfall	1	5	0.833
Temp	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert 4	Rainfall	Temp	Weight
Rainfall	1	1/5	0.167
Temp	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert 5	Rainfall	Temp	Weight
Rainfall	1	1/5	0.167
Temp	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert6	Rainfall	Temp	Weight
Rainfall	1	7	0.875
Temp	1/7	1	0.125
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert7	Rainfall	Temp	Weight
Rainfall	1	3	0.75
Temp	1/3	1	0.25
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert8	Rainfall	Temp	Weight
Rainfall	1	5	0.833
Temp	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert9	Rainfall	Temp	Weight
Rainfall	1	1/5	0.167
Temp	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert10	Rainfall	Temp	Weight
Rainfall	1	3	0.75
Temp	1/3	1	0.25
CR=CI/RI= 0/0=0 (λmax= 2)			

Factors	Rainfall	Temp	Rank	Rank/range	Weight
Rainfall	1	7	8	8/10=0.8	0.667
Temp	3	1	4	4/10=0.4	0.333
				1.2	1.00

Level 3: Bio-physical: Soil (Drainage, Depth, Texture)

Expert1	Drainage	Depth	Texture	Weight
Drainage	1	3	5	0.636986
Depth	1/3	1	3	0.258285
Texture	1/5	1/3	1	0.104729
CR=CI/RI= 0.019/0.58=0.03 <0.1 (λ_{max}=3.03851)				
Expert2	Drainage	Depth	Texture	Weight
Drainage	1	5	7	0.730645
Depth	1/5	1	3	0.188394
Texture	1/7	1/3	1	0.0809612
CR=CI/RI=0.032/0.58= 0.51<0.1 ((λ_{max}=3.06489)				
Expert3	Drainage	Depth	Texture	Weight
Drainage	1	7	3	0.636986
Depth	1/7	1	1/5	0.258285
Texture	1/3	5	1	0.104729
CR=CI/RI=0.032/0.58= 0.51<0.1 ((λ_{max}=3.06489)				
Expert4	Drainage	Depth	Texture	Weight
Drainage	1	5	3	0.636986
Depth	1/5	1	1/3	0.104729
Texture	1	3	1	0.258285
CR=CI/RI= 0.019/0.58=0.03 <0.1 (λ_{max}=3.03851)				
Expert5	Drainage	Depth	Texture	Weight
Drainage	1	3	5	0.636986
Depth	1/3	1	3	0.258285
Texture	1/5	1/3	1	0.104729
CR=CI/RI= 0.019/0.58=0.03 <0.1 (λ_{max}=3.03851)				
Expert6	Drainage	Depth	Texture	Weight
Drainage	1	3	7	0.649118
Depth	1/3	1	5	0.278955
Texture	1/7	1/5	1	0.071925
CR=CI/RI=0.032/0.58= 0.51<0.1 ((λ_{max}=3.06489)				
Expert7	Drainage	Depth	Texture	Weight
Drainage	1	1/3	3	0.258285
Depth	3	1	5	0.636986
Texture	1/3	1/5	1	0.104729
CR=CI/RI= 0.019/0.58=0.03 <0.1 (λ_{max}=3.03851)				
Expert8	Drainage	Depth	Texture	Weight
Drainage	1	1/5	3	0.188394
Depth	5	1	7	0.730645
Texture	1/3	1/7	1	0.0809612
CR=CI/RI=0.032/0.58= 0.51<0.1 ((λ_{max}=3.06489)				

Level 3: Bio-physical: Soil (Drainage, Depth, Texture)(continued)

Expert9	Drainage	Depth	Texture	Weight
Drainage	1	1/3	1/5	0.104729
Depth	3	1	1/3	0.258285
Texture	5	3	1	0.636986
CR=CI/RI= 0.019/0.58=0.03 <0.1 (λ_{max}=3.03851)				
Expert10	Drainage	Depth	Texture	Weight
Drainage	1	1/3	1/7	0.0809612
Depth	3	1	1/5	0.188394
Texture	7	5	1	0.730645
CR=CI/RI=0.032/0.58= 0.51<0.1 ((λ_{max}=3.06489)				

Factors	Drainage	Depth	Texture	Rank	Rank/range	Weight
Drainage	1	6	8	15	15/20= 0.75	0.4545
Depth	4	1	6	11	11/20= 0.55	0.3334
Texture	2	4	1	7	7/20= 0.35	0.2121
				33	1.65	1.00

Level3: Socio-economic: Livelihood (Population density vs Available land use)

Expert1	Population	Land use	Weight
Population	1	1/3	0.25
Land use	3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert2	Population	Land use	Weight
Population	1	5	0.833
Land use	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert3	Population	Land use	Weight
Population	1	1/9	0.1
Land use	9	1	0.9
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert4	Population	Land use	Weight
Population	1	3	0.75
Land use	1/3	1	0.25
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert5	Population	Land use	Weight
Population	1	5	0.833
Land use	1/5	1	0.167
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert6	Population	Land use	Weight
Population	1	1/3	0.25
Land use	3	1	0.75
CR=CI/RI= 0/0=0 (λmax= 2)			

Level3: Socio-economic: Livelihood (Population density vs Available land use) (continued)

Expert7	Population	Land use	Weight
Population	1	1/5	0.167
Land use	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert8	Population	Land use	Weight
Population	1	1/9	0.1
Land use	9	1	0.9
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert9	Population	Land use	Weight
Population	1	3	0.75
Land use	1/3	1	0.25
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert10	Population	Land use	Weight
Population	1	3	0.75
Land use	1/3	1	0.25
CR=CI/RI= 0/0=0 (λmax= 2)			

Factors	Population	Land use	Rank	Rank/range	Weight
Population	1	5	6	5/10=0.6	0.500
Land use	5	1	6	7/10=0.6	0.500
				1.2	1.00

Level3: Socio-economic: Distance (Distance from main road vs distance from river)

Expert1	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert2	Road	River	Weight
Road	1	9	0.9
River	1/9	1	0.1
CR=CI/RI= 0/0=0 (λmax= 2)			
Expert3	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Level3: Socio-economic: Distance (Distance from main road vs distance from river)(continued)

Expert4	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert5	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert 6	Road	River	Weight
Road	1	7	0.875
River	1/7	1	0.125
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert 7	Road	River	Weight
Road	1	9	0.9
River	1/9	1	0.1
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert 8	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert 9	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Expert 10	Road	River	Weight
Road	1	1/5	0.167
River	5	1	0.833
CR=CI/RI= 0/0=0 (λmax= 2)			

Factors	Road	River	Rank	Rank/range	Weight
Road	1	3	4	4/10=0.4	0.34
River	7	1	8	5/10=0.8	0.66
				1.2	1.00

APPENDIX H

Pair Wise Comparison for priority setting of land use planning of URB

	HSA	HSU	MSA	MSU	LSA	LSU	Weight	Priority
HSA	1	3	4	5	6	7	0.425726	First
HSU	1/3	1	3	4	5	6	0.253863	Second
MSA	1/4	1/3	1	3	4	5	0.14958	Third
MSU	1/5	1/4	1/3	1	3	4	0.0876558	Fourth
LSA	1/6	1/5	¼	1/3	1	3	0.0516962	Fifth
LSU	1/7	1/6	1/5	1/4	1/3	1	0.0314791	Sixth
CR= CI/RI=0.00939/1.24 = 0.075 < 0.1							1.000	

Pair Wise Comparison for priority setting of Scenario 3

	HSF	HSA	HSU	MSF	MSA	MSU	LSF	LSA	LSU	W	Priority
HSF	1	2	3	4	5	6	7	8	9	0.31211	First
HSA	1/2	1	2	3	4	5	6	7	8	0.22342	Second
HSU	1/3	1/2	1	2	3	4	5	6	7	0.15546	Third
MSF	1/4	1/3	1/2	1	2	3	4	5	6	0.10750	Fourth
MSA	1/5	1/4	1/3	1/2	1	2	3	4	5	0.07385	Fifth
MSU	1/6	1/5	1/4	1/3	½	1	2	3	4	0.05066	Sixth
LSF	1/7	1/6	1/5	1/4	1/3	1/2	1	2	3	0.034997	Seventh
LSA	1/8	1/7	1/6	1/5	¼	1/3	1/2	1	2	0.024723	Eighth
LSU	1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1	0.018337	Ninth
CR= CI/RI= 0.0501/1.24=0.04 < 0.1											

APPENDIX I

Multiple Regression Equations

Model	WQP	Independent variables	Regression equation	R^2	Adjusted R^2	F	Sig.
1	TEMP	Urban, forest, water body	TEMP = 26.517 + 0.145 URB + 0.078 FOR + 0.055 WTB	0.655	0.597	11.36	0.000
2	pH	Agriculture	pH = 4.459 + 0.025 AGR	0.319	0.283	8.897	0.008
3	EC	Agriculture	EC= -157.698+ 3.0122 AGR	0.237	0.195	5.597	0.029
4	DO	Agriculture, forest	DO= -2.337+ 0.072 AGR + 0.047 FOR	0.530	0.495	15.208	0.000
5	BOD	Agriculture, urban	BOD= 5.535- 0.024 AGR + 0.117 URB	0.560	0.527	17.172	0.000
6	SS	Forest, agriculture, urban	SS = -523.033+3.447 FOR + 7.662 URB + 6.555 AGR	0.568	0.424	3.948	0.047
7	DS	Forest, urban, water body	DS = -6.948+5.551 FOR + 4.896 URB + 5.305 WTB	0.563	0.537	21.477	0.000
8	FCB	Agriculture, urban, water body	FCB = 329431.478 – 3669.563 AGR- 2908.470 URB – 2963.194 WTB	0.507	0.442	7.876	0.001
9	TUR	Agriculture	TUR=193.005-2.036 AGR	0.222	0.027	1.140	0.346
10	TP	Agriculture	TP= 13.299-0.0160 AGR	0.250	0.062	1.330	0.313
11	NO_3	Urban	NO3=1.092+0.03 URB	0.159	0.129	5.292	0.029
12	NO_2	Forest	NO2= 1.390-0.047 FOR	0.314	0.143	1.833	0.247
13	NH_3	Urban	NH3=0.478+0.03 URB	0.293	0.192	2.895	0.133

VITAE

Name: Saroj Gyawali

Date of birth: 12 July 1972

Student ID: 5210930017

Educational Attainment:

Degree	**Name of Institute**	**Year of Graduation**
Intermediate in Science (I. Sc.)	Tri-Chandra Campus Tribhuvan University Kathmandu, Nepal	1990
Bachelor’s Degree in Science (B. Sc.)	Amrit Science Campus Tribhuvan University Kathmandu, Nepal	1994
Master in Science (M Sc)	Faculty of Statistics Tribhuvan University Kathmandu, Nepal	1996

List of Publications and Proceedings

Publications

Gyawali, S., Techato, K., Yuangyai, C., & Monprapussorn, S. (2012). Evaluation of surface water quality using Multivariate statistical techniques: A case study of U-tapao river basin, Thailand. *KMITL Science and Technology Journal,* 12(1), 7-20.

Gyawali, S., Techato, K., Yuangyai, C., & Monprapussorn, S. (2012). Assessment surface water quality parameters and their variations for effective monitoring system, A case study of U-tapao River Basin. *Journal of Environmental Research,* 34 (2), 89-106.

Proceedings

Gyawali, S., Techato, K., Monprupussorm, S., & Yuangyai, C. (2011). *Integrating land use and water quality for environmental based land use planning for U-tapao river basin, Thailand*. Conference proceeding PUS-USM International Conference, Hatyai, Songkhla, Thailand, 3-4 October, 2011.

Gyawali, S., & Techato, K. (2011). *The influence of agricultural land use on water quality of U-tapao river, Thailand*. Conference proceeding, The 2nd

International conference on sustainability future for human security-SUSTAIN 2011, Kyoto, Japan, 8-9 October, 2011.

Gyawali, S., Techato, K., & Yuangyai, C. (2011). *The improvement of water quality monitoring system of U-tapao river basin, Thailand*. Conference proceeding, ITCHE International conference, Hatyai, Thailand, 10-11 November, 2011.

Gyawali, S., Techato, K., & Yuangyai, C. (2012). *Effects of Industrial waste disposal on the surface water quality of U-tapao river, Thailand*. Conference proceeding, International conference on environmental and chemical engineering, Bangkok, Thailand, April 7-8, 2012.

Gyawali, S., Techato, K., Chumpol, Y., & Monprapussorn, S. (2012). *The Influence of Urbanization on Water Quality of U-tapao River, Thailand*. Conference proceeding, International Conference on Green and Sustainable Innovation, Chiang Mai, May 24-26, Thailand.

Gyawali, S., Techato, K., Titseesang, T., & Monprapussorn, S (2012). *A study of relationship of land-use patterns and surface-water quality for sustainable development of river basin*, Srinakharinwirot Conference, 29-30, May, Thailand.