Doctoral Dissertation

Assessing Land Use and Land Cover Change toward Sustainability in Humid Tropical Watersheds, Indonesia

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Assessing Land Use and Land Cover Change toward Sustainability in Humid Tropical Watersheds, Indonesia

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Abbreviations and Acronyms

AGNPS	:	Agricultural Nonpoint Source Pollution Model
ANOVA	:	Analysis of variance(s)
ANSWERS	:	Areal Nonpoint Source Watershed Environment Response Simulation
APN	:	Asia Pacific Network
ASTER	:	Advanced Space-borne Thermal Emission and Reflection Radiometer
ASL	:	Above Sea Level
BOD	:	Biological Oxygen Demand
BPDAS	:	Balai Pengelolaan Daerah Aliran Sungai (in English: Center of Watershed Management)
BSN	:	Badan Standarisasi Nasional (in English: National Standarization Agency of Indonesia)
CGIAR	:	Consultative Group on International Agricultural Research
CIESIN	:	Center for International Earth Science Information Network
CO_2	:	Carbon dioxide
COD	:	Chemical Oxygen Demand
DEM	:	Digital Elevation Models
DN	:	Digital Number(s)
DO	:	Dissolved Oxygen
DPSIR	:	Driving Force-Pressure-State-Impact-Response
DSR	:	Driving Force-State-Response
EEA	:	European Environmental Agency
EF	:	Ecological Footprint
EIM	:	Eco-Index Methodology
EPI	:	Environmental Performance Index

EPI	:	Environmental Pressure Index
EQI	:	Environmental Quality Index
ERDAS	:	Earth Resources Data Analysis System
ETM	:	Enchanced Thematic Mapper
EVI	:	Environmental Vulnerability Index
FAO	:	Food and Agriculture Organization
FDES	:	Framework for the Development of Environmental Statistics
GCP	:	Ground Control Point
GDEM	:	Global Digital Elevation Model
GDP	:	Gross Domestic Product
GDRP	:	Gross Domestic Regional Product
GHG	:	Greenhouse Gas
GIS	:	Geographical Information Systems
GLP	:	Global Land Project
HELP	:	Hydrology, Environment, Life and Policy
HDI	:	Human Development Index
IEF	:	Index of Environmental Friendliness
IGBP	:	International Geosphere Biosphere Program
IHDP	:	International Human Dimensions Program on Global Environemntal Change
ISO	:	International Organization for Standardization
KINEROS	:	Kinematic Wave Overland Flow, Channel, Routing and Erosion Model
KNSP	:	Kerinci Seblat National Park
LANDSAT	:	LAND + SAT(ellite)
LCS	:	Land Change Science
LISEM	:	Limburg Soil Erosion Model
LPI	:	Living Planet Index

LPN	:	Land Policy Network
LRA	:	Land Research Associates
LUCID	:	Land Use Change, Impacts and Dynamics
LULC	:	Land Use and Land Cover
MLC	:	Maximum Likelihood Classifier
NO_3N	:	Nitrate
OECD	:	the Organization for Economic Cooperation and Development
P	:	Phosphate
PV	:	Permisible value
PPI	:	Population Pressure Index
PSR	:	Pressure-State-Response
RMS	:	Root Mean Square
RS	:	Remote Sensing
RUSLE	:	Revised Universal Soil Loss Equation
SA	:	Sustainability Assessment
SPI	:	Sustainability Performance Index
SPOT	:	Système Pour l'Observation de la Terre
SPSS	:	Statistical Package for the Social Sciences
SRTM	:	Shuttle Radar Topography Mission
STORET	:	STOrage and RETretrieval
STREAM	:	Sealing, Transfer, Runoff, Erosion, Agricultural Modification
SWAT	:	Soil Water Assessment Tool
TDS	:	Total Dissolved Solids
TSS	:	Total Suspended Solids
UN	:	United Nations
UN-ESCAP	:	United Nations – Economic and Social Commission for Asia and the Pacific

UNEP	:	United Nations Environment Programme
UNESCO	:	United Nations Educational, Scientific and Cultural Organization
USGS	:	United States Geological Survey
USLE	:	Universal Soil Loss Equation
UTM	:	Universal Transverse Mercator
Wa	:	Water availability
WATEM	:	Water and Tillage Erosion Model
WCED	:	World Commission on Environmental and Development
WEPP	:	Water Erosion Prediction Project
WGS	:	World Geodetic System
WGWMD	:	the Working Group on Watershed Management and Development
WMO	:	World Meteorological Organization
WPI	:	Water Pollution Index
WSI	:	Watershed Sustainability Index

Abstract

RACHMAD FIRDAUS
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Supervised by Prof. Nobukazu NAKAGOSHI
Title : Assessing Land Use and Land Cover Change toward Sustainability in Humid Tropical Watersheds, Indonesia (**200 pp**)

Land use and land cover (LULC) change is increasingly considered as an important component of sustainability studies particularly in landscape change. It is also a central part of global environmental changes in current strategies for managing natural resources. In Indonesia so far many researches related to analyzing LULC change and its ecological impacts. Due to research priority, there is a present and growing need to assess the sustainaibility level of watesheds in Indonesia. The originality, as well as the main purpose of of this study, is that it is the first attempts in assessing LULC change toward sustainability or degree of watershed sustainability in humid tropical watersheds in Indonesia.

The landscapes focus of this research are the two selected watersheds humid tropical watesheds in Indonesia, which are located in Sumatera island (Batang Merao watershed) and Java island (Cirasea sub-watershed). Batang Merao watershed, a representative of the little known land change in humid tropical region in Indonesia, is one of the key regions of LULC research and plays an important role in maintaining the conservation function of Kerinci Seblat National Parks and socioeconomic function of Jambi Province, Indonesia. Cirasea sub-watershed, a representative of the Indonesian's most densely populated watersheds, was also selected for this research because it is one of the most important sub-watersheds of Citarum watershed, a main water resource

in West Java. Cirasea sub-watershed has a prominent role as a conservation area and buffer zone of ecosystem in relation to other regions. Environmental degradations in this landscape can disturb the sustainability of conservation and cultivation functions. In addition, it had undergone substantial land use and land cover change and it was subject to high population pressure.

Chapter 1 primarily presents an overview of dissertation including background of the study, statement of research problem, aim and objectives, the significance of the study, scientific contribution of the study and and structure of the dissertation.

Chapter 2 consists of theoretical background and methodological approaches, i.e. theory of LULC, analysis of LULC, theory of watershed and watershed management, theory and aplication of sutainability and its assessment, general description of watershed management in Indonesia and technical steps of general methodological approaches.

Chapter 3 aims to investigate dynamic patterns and driving forces of LULC, and population pressure from 2006 to 2011. Dynamic patterns have been investigated with GIS and Remote Sensing techniques, driving forces have been analyzed with multiple regressions combining biophysical and socioeconomic variables, whereas population pressure has been quantified with Population Pressure Index (PPI). The results indicated that dynamic of LULC showed an increase in agricultural area (mix plantation and agricultural land), with mainly at the expense of forest and shrub/bush. On the contrary, forest area decreased from 24.20% in 2006 to 18.13% in 2011 respectively. Annual rate of LULC change clearly showed that the dynamics of different LULC classes over the study periods. The socioeconomic driving factors that significantly involved in the dynamic of LULC change were population growth/pressure, number of farmers, GDRP agriculture, GDRP total, and Human Development Index (HDI). Change in LULC and its dynamics were closely associated with human activities in the region such as the expansion of agricultural area. The results are critically important for sustainable watershed management where agriculture is the major income for most people in and around the watershed.

The first section of chapter 4 aims to determine the relationship between land use land cover (LULC) changes and land degradation using multi temporal Landsat data from 1990, 2000 and 2010. The results showed that during the last two decades, two major changes took place. Forest decreased at rates of 330.85 ha y^{-1} (period of 1990-2000) and 145.25 ha y^{-1} (period of 2000-2010); on the other hand, agricultural land, mix plantation, and settlement have shown increments. Concerning land degradation, Batang Merao watershed exhibited potential soil degradation where the mean annual potential land degradation was 128.03 ton ha^{-1} y^{-1} in 1990, 144.68 ton ha^{-1} y^{-1} in 2000 and 194.14 ton ha^{-1} y^{-1} in 2010. This study reveals that there is relationship between LULC change and land degradation that land cover type plays an important role in protecting soil from land degradation in this watershed. In order to prevent the areas from an extremely high level of land degradation, the proper use of land cover and soil conservation program are highly recommended to be widely implemented.

The second section of chapter 4 investigates the relationship between LULC and water quality in the watershed. The water quality parameters were analyzed by using the Water Pollution Index (WPI) and STOrage and RETrieval (STORET) methods as the national standard of river water quality in Indonesia. Analysis of variance, correlation analysis, and stepwise multiple regression analysis were used to investigate spatial and temporal variations of LULC, water quality, and the relationship between them. The water quality study revealed that Batang Merao watershed was classified as lightly polluted (86.67%) and moderately polluted (13.33%) meanwhile, the STORET results indicated that about 80% of them were moderately polluted. Statistical analysis showed that there was a relationship between LULC and water quality parameters. As implication that there is a growing need to evaluate the status of water quality in order to anticipate its potential negative impacts of water quality degradation in the watershed.

Chapter 5 examines LULC change, population pressure and priority determination on handling land degradation in West Java, as a comparative study. The results of this study showed that most areas of Cirasea sub-watershed where high soil erosion, population pressure and degraded land areas that were more much higher and complex than the condition in Batang Merao watershed. This case study contributes to the direction of handling land degradation at watershed scale. Because of the high population growth, it should be better to involve people participation in the soil conservation and reforestation program.

Chapter 6 aims to assess the sustainability of Batang Merao Watershed for the period of 2006-2011 using HELP (Hydrology, Environment, Life and Policy) indicators. The results showed, the watershed was at an intermediate level of watershed sustainability (overall WSI score = 0.59) and was still in high pressure due to its pressure parameter, which was higher than both state and the response parameters. This mean that this watershed needs kind of improvement or management to reach the better level of sustainability (>0.59). Therefore, it is urgent to improve the integrated watershed management programs for achieving the sustainability of this watershed.

Finally, Chapter 7 generally discusses the major findings and the implications of the study, recognizes the limitation of the study, suggests direction for future research, and finally gives recommendations.

The main contribution of this study is that it was successful in assessing LULC change and its ecological impacts, and could contribute to land and watershed planning in order to achieve sustainability in humid tropical watersheds in Indonesia. On the conceptual level, the research highlights the dynamic and complex relationship of LULC change at the watershed level. In terms of the methods, this research invite the open room and challenge of bringing together various data sources and methods toward sustainability in humid tropical watersheds. Finally, this research is a kind of pioneer in successfully assessing the sustainability in Batang Merao Wateshed. Therefore, in Indonesia perspective, what we have done hopefully will be followed by the policy makers related watershed management.

Chapter 1

Introduction

1.1 Background of the study

Humid tropical regions, the area within the Equator and 25° in both the Northern and Southern Hemispheres, and include areas in which precipitation exceeds evaporation for at least 270 days per year, occupy about one fifth of Earth's land surface (Wohl et al., 2012). Yet, they contribute a substantially higher fraction of the water, solutes, and sediment discharged to the world's oceans (Murphy and Stallard, 2012). Relative distribution of the humid tropics comprises approximately 750 million ha in Latin America (45%), 340 million ha in Africa (30%), and 220 million ha in Asia (25%). More than 2.6 billion from about 60 countries (Lal, 1995) live in the humid tropics depend directly or indirectly on agriculture and have difficulty responding to social, political, economical, cultural, biological and environmental pressures despite their uniqueness and complexity (CGIAR, 2012). As consequences, humid tropics are at the same time critical to global supplies of basic food stuffs, central to the maintenance of global biodiversity and the mitigation of greenhouse gases, and yet offer the largest potential for meeting world food demand over the next several decades (CGIAR, 2012). In addition, agricultural activity in most tropical country increased its food production mainly by increasing fertilizer use and irrigation (Ramankutty et al., 2006) that give negative impacts on land and water.

Destruction of humid tropical forests has become a key global concern (Barbier, 1990) due to the significance of forest on global climate, carbon sequestration, water cycles, biodiversity and the potential global effects on climate change (Hansen et al., 2008). The world's humid tropical forests are under considerable pressure, resulting in high deforestation rates and increasing degradation of 2.3 ± 0.7 Mha annually (Achard et al., 2002). In the period of 1981-1990, the overall rate of deforestation of 0.6% per year and nearly 9 ha per minute, but the rate was almost twice this in Asia (FAO, 1993). Between 1990 and 1997, about 5.8 ± 1.4 million hectares of humid tropical forest were lost each year, with a further 2.3+0.7 milion hectars of forest visibly degraded (Achard et al., 2002). In the period 1990-2000 the world is estimated to have suffered a net loss of 8.9 million hectares of forest each year, but in the period 2000-2005 this was reduced to an estimated 7.3 million hectares per year (FAO, 2006). In broader terms, this means that the world lost about 3 per cent of its forests in the period 1990 to 2005; at present we are losing about 200 square kilometres of forest each day (UNEP, 2009). Water resource is also under pressure in the humid tropics from population growth, land use and climate change, all of which are influenced by humans (Wohl et al., 2012). Converting land from forest other land use types will generate environmental and social costs (Lambin and Meyfroidt, 2011). One study estimated that total cost of forest conversion and degradation in Indonesia to be approximately 4% of Gross Domestic Product (GDP) (Barbier, 1990).

Land use change has generally been considered a local environmental issue, but it is becoming a force of global importance (Foley et al., 2005). Changes in land and their implications for global environmental change and sustainability are a major research challenge for the human environmental sciences (Turner et al., 2007). Global changes in land use and climate also have highlighted the role of ecosystems in food, water, and energy security and in climate change mitigation and adaption (Goldstein et al., 2012). Land use change has played a role in changing the global carbon cycle and accounts for roughly 35% of anthropogenic CO_2 emissions resulted (Foley et al., 2005). Much of this change is a direct consequence of land uses: 40% of land surface is in agriculture (Turner et al., 2007). Currently, in many parts of the world, human activity is the major force in shaping LULC change although the underlying physical structure of landscape may constrain LULC (Su et al., 2011). Therefore, an integration of biophysical and human factors in the explanation of LULC dynamics remains as an important research task. Understanding the causes and consequences of land change is one of the prime goals of global change research (Rindfuss et al., 2004). As a consequence, information about land use change is necessary for effective management and planning of the resources for sustainable development (Anil et al., 2011). Accurate and up-to-date land cover change information is necessary to understand and assess the environmental consequences of such changes (Lambin and Geist, 2007). There is a continuing demand for up-to-date LULC information for any kind of sustainable development programm where LULC serves as one of the major input criteria. This research is taken up to better understand LULC change in humid tropical watersheds particularly in Indonesian watersheds.

There is a growing international concerns on themes that are central to understanding land-use and land-cover change as a major driver of environmental change (Braimoh and Osaki, 2010). On the global scale, the Global Land Project (GLP), jointly established by the International Human Dimensions Program on Global Environmental Change (IHDP) and the International Geosphere Biosphere Program

(IGBP), is the foremost international global change project promoting land change science (LCS) for environmental sustainability seeking to integrate a range of research questions towards an improved understanding of the dynamics of land change, the causes and consequences of land change, and assessment of system outcomes, notably vulnerability and resilience of land systems (Turner et al., 2007). In addtion, there are regional network for land change research and development such as Land Use Change, Impacts and Dynamics (LUCID) network for Africa, Asia Pacific Network for Global Change Research (APN) for Asia Pacific, and Land Policy Network (LPN) for Latin America. Also, there are many independent research centers and networks such as the Center for International Earth Science Information Network (CIESIN) and Land Research Associates (LRA). The last 10 years have seen dramatic advances in the ability of scientific communities to simulate important interactions in the Earth system (Hibbard et al., 2010). It can be an open room that advancement in LCS in the coming years vis-a`-vis realizing or improving theories of land change (Braimoh and Osaki, 2010).

LCS has emerged as a fundamental component of global environmental change and sustainability research (Turner et al., 2007) both for basic science and applied science themes (Aspinall, 2008). The there main reasons why LCS is an emerging issue are its critical to the global environment, given priority over long time concerns, having a large spatial scale, and recognizing as ‘emerging’ based on newness which can be the result of: new scientific knowledge, new scales, accelerated rates of impact, heightened level of awareness, and new ways to respond to the issue (UNEP, 2012a). The major components and advances in land change are addressed: observation, assesing and monitoring; understanding the coupled system—causes, impacts, and consequences; modeling; and synthesis issues (Lambin et al., 2006; Lang et al., 2012; Turner et al., 2007). In particular, there is a growing literature of research focusing on tropical LULC change (Hibbard et al., 2010). It is mainly because LULC change in humid tropical region has undergone dramatic LULC change in the last few decades, and these changes are the effect of an equally large number of local causes and factors (Mejía and Hochschild, 2012). As a consequence, information about LULC is essential for any kind of natural resource management and action planning. The prior advantage of LULC study is that it is one of the most precise techniques to understand LULC mechanism, what types of changes are to be expected in the future, as well as the forces and processes behind the changes, valuable information for the analysis of the environmental impacts, population pressure, agriculture expansion, deforestation, resettlement program, climate change, and others. Timely and precise information about LULC change is extremely important for better management of decision making. There is a continuing demand for up-to-date LULC information for any kind of a sustainable development program where LULC serves as one of the major input criteria.

Concerns about the sustainability of humid tropical watersheds are a strong motivation to better understand integrated watershed management (Wagner et al., 2002). The importance of watershed sustainability has become more relevant because of the increasing awareness that the sustainability of watershed functions is an essential requisite for a sustainable future and human security. A watershed-based approach offers an excellent scope for the assessment and management of environmental problems (Randhir, 2007) and has been viewed as useful systems for planning and implementing natural resource and agricultural development for many centuries

(Brooks and Eckman, 2000). Because sustainable watershed management is a central challenge in the context of sustainable development (Swami and Kulkarmi, 2011), its management has to ensure human security and protect environment from negative consequences such as ecosystem degradation, pollution, and climate change. Unfortunately, for most countries particularly in humid tropical region, watershed management is still viewed from the narrow perspective of benefits to water projects alone while it should be in holistic perspective and should be considered essential for soil and water conservation (Biswas, 1990). For example, watershed management in Indonesia suffers from a number of problems caused by a failure to apply the basic concepts underlying the sound management of watershed approach (Anwar, 2003). However, assessing watershed management and its sustainability can be used to determine the changes to ecosystem health and productivity associated with land management practices (Randhir, 2007). Therefore, this study highlights issues that require integrated indicators in assessing the level of sustainability associated with watershed management.

Indonesia, a developing country which is amongst three mega biodiversity countries in Southeast Asia (Subramanian et al., 2011) and which population has grown rapidly as the fourth most populous country in the world, also faces many environmental degradation in due to LULC change. As Indonesia is now under environmental pressure, it is also often seen as a country of environmental ruin whose biodiversity degradation is in alarming rates (Ministry of Environment Indonesia, 2009). Among tropical regions, Indonesia exemplifies this critical situation and experiences one of the highest rates of deforestation due to land change such as agricultural expansion, deforestation and habitat fragmentation. Study on absolute environmental metrics has attempted Indonesia as the 2nd worst country based on natural forest loss (Bradshaw et al., 2010). The predominance of Indonesia in humid tropical forest clearing accounts for 12.8% of the total forest loss (Hansen et al., 2008).

It is proved that tropical watersheds in Indonesia are amongst the most fragile terrestrial landscape. The critical watershed in Indonesia has identified 22 watersheds in 1984 and has reached up to 60 in 1998 (Tanaka et al., 2010) and becomes worse indicated by the increasing number of critical land degradation in the watershed from approximately 77 million ha in 2006 to 82 million ha in 2011 (Ministry of Forestry of Indonesia, 2010). The extent of these critical watersheds influences strongly on the regional hydrological condition and the water resources status (Tanaka et al., 2010). Also, water resources is becoming crucial issue because of the rapid population growth and accompanied changes of land use, yet the management for sustainable water resources are still facing many constraints and growing up very severe problems that water scarcity, drought, flood, water pollution and many other related things (Tanaka et al., 2010). This condition, furthermore, will give negative impacts to the sustainable function of biodiversity, water and other ecosystem services.

In other studies that have been taken about LULC issues at national level in Indonesia reported that the problems are become more complex, and cover various aspects of inappropriate policy implementation, socioeconomic, and political issues (Resosudarmo et al., 2012). Hence, region-specific information of such LULC change study is essential for land use planning aiming at wise resource management at watershed level.

1.2 Statement of the research problem

Our current understanding of LULC change in humid tropical watersheds especially in Indonesia is inadequate. The lack of an understanding of the trends in the change of LULC in relation to the watershed sustainability in the study areas currently impedes planning processes at the watershed level. Further understanding of LULC change and watershed sustainability need to be greatly improved LULC change research. In order to better understand LULC change and its relationship to watershed sustainability, it will be necessary to conduct studies that explicitly reveal the pattern, driver, ecological impacts and sustainability of LULC in the study area. This research will address relevant issues on LULC change in relation to the socioeconomic of the watershed and provide recommendations which may contribute to the watershed sustainability; and to the forest, soil and water conservation in the study area.

In Indonesia so far many researches related to analyzing LULC change and its ecological impacts. Due to research priority, there is a present and growing need to assess the sustainaibility level of all watesheds in Indonesia. Therefore, for the priority of this research is to assess LULC change toward watershed sustainability in Indonesia.

Nevertheless, there is no such critically investigated LULC studies carried out in and around the study areas both Batang Merao watershed (Sumatera Island) and Cirasea sub watershed (Java Island) so far. Both study areas can represent humid tropical watersheds in Indonesia. The first one adequately characterized Sumateran tropical rainforest with a relatively sparse population while the other one represents the dominantly tea plantation with high population density and high agricultural land necessity.

In landscape ecology, the need for study at multiple scales has been done through a new apporaches to assess landscape patterns, processes and ecological impacts (Bürgi et al., 2004; Francoise and Boudry, 2003; Lambin et al., 2006). There is also a growing need to quantitatively assess potential land and water quality degradation and the sustainability level of the watershed. Therefore the study of LULC change toward watershed sustainability is paramount to combating environmental degradation and better environmental resource management.

1.3 Aim and objectives of the study

To address the above mentioned problem, the aim of the study is to assess LULC change towards sustainability in humid tropical watersheds in Indonesia. The focus is placed on the Batang Merao watershed and Cirasea sub-watershed, and more generally in Indonesia.

The achievement of the main purpose is based on the following specific objectives:

1. To investigate the dynamic pattern and driving force of LULC change in Batang Merao watershed, from 2006 to 2011.
2. To determine the population pressure level in Batang Merao watershed, from 2006 to 2011.
3. To investigate the relationship between LULC change and land degradation in the Batang Merao watershed, from three different periods of 1990, 2000, and 2010.
4. To assess the relationship between LULC change and water quality status in humid tropical watersheds: a case of Batang Merao watershed, Indonesia.

5. To investigate changes in LULC and priority determination on handling land degradation in Cirasea sub-watershed, West Java (as a comparative study).
6. To assess the sustainability in Batang Mearo watershed, Indonesia.

1.4 Significance of the study

1. With its outstandingly rich in biodiversity (Kartasubrata, 1993) and significantly role in humid tropics, Indonesia, therefore has a great responsibility to maintain forest, land and watershed sustainability.
2. Because watershed management is a central part in the context of sustainable development (Swami and Kulkarmi, 2011), the importance of watershed sustainability has become more relevant that the sustainability of watershed functions is an essential requisite for a sustainable future both for ecosystem and human security.
3. Numerous studies have focused on evaluating land use status, focusing detail technical method and model, studying driving land use and ecological impacts partially (Wang and Wang, 2013). However, these studies lack comprehensive LULC in relation to sustainability of the study area. Especially, studies on LULC change with sustainability of the watershed are relatively weak in humid tropical regions.
4. So far, there has been limited research documentation on LULC change in Indonesia and its impacts on the environment to deepen the understanding of linking human and LULC dynamic and to serve the sustainable watershed

management. The hope that this research will be useful, not only in managing watershed but also for planning and policy making.

5. The knowledge gained from this research could be used to better understanding for land planning and watershed management. A better understanding of the processes, rates, causes, and consequences of LULC change is vital for many areas of global change research (Braimoh and Vlek, 2004) including patterns and process (Wang and Wang, 2013), driving forces (Bürgi et al., 2004), impacts (Mahmood et al., 2010), and policy implementation (Hibbard et al., 2010). Therefore, this scientific information will be invaluable not only to academia but also to the watershed/landscape managers, local government in Indonesia to control negative effects of LULC change and to manage watershed properly.

1.5 Scientific contribution of the study

In regard to the scientific consideration and responsibility, there are six scientific papers become the backbone of the dissertation as follows:

1. Rachmad Firdaus and Nobukazu Nakagoshi, 2013. Dynamic patterns and socioeconomic driving forces of land use and land cover change in humid tropical watersheds: a case study of Batang Merao watershed, Indonesia, International Research Journal of Environmental Science, Vol.2, No. 12, pp.89-96. (***chapter 3***)
2. Rachmad Firdaus et al., 2013. The relationship between land use and land cover, and land degradation of natural protected area in Batang Merao Watershed, Indonesia, Book Chapter: Designing Low Carbon Societies in Landscape,

Springer, (Accepted September 30, 2013; will be published Early 2014). (***chapter 4 section 1***)

3. Rachmad Firdaus and Nobukazu Nakagoshi, 2013. Assessment of the relationship between land use land cover and water quality status of the tropical watershed: a case of Batang Merao Watershed, Indonesia, Journal of Biodiversity and Environmental Science, Vol. 3, No.11, pp. 21-30. (***chapter 4 section 2***)
4. Rachmad Firdaus et al., 2011. Changes in land use/land cover and priority determination on handling land degradation in Cirasea sub-watershed, West Java, Hikobia Journal, Vol. 16, No. 1, pp. 9-20. (***chapter 5***)
5. Rachmad Firdaus et al., 2013. Sustainability assessment of Humid Tropical Watershed: a case of Batang Merao watershed, Indonesia, Procedia of Environmental Science, (Accepted: November 30, 2013; will be published January 2014). (***chapter 6***)

1.6 Dissertation Structure

The dissertation outline can be divided into seven chapters. The first chapter is the introduction which primarily gives the aim of the present research work. The rest of the thesis is arranged as follows: Chapter 2 consists of several relevant theoretical background and methodological approaches for this study. Chapter 3 describes patterns and driving forces of LULC change. Chapter 4 is allocated for the analyses of ecological impacts of LULC on both land degradation water quality. Chapter 5 describes the results of LULC change in West Java, as a comparative study. Chapter 6 examines the watershed sustainability. The last part, chapter 7, is the general discussion and conclusion of this dissertation. Thesis flowchart is shown in Figure 1.1.

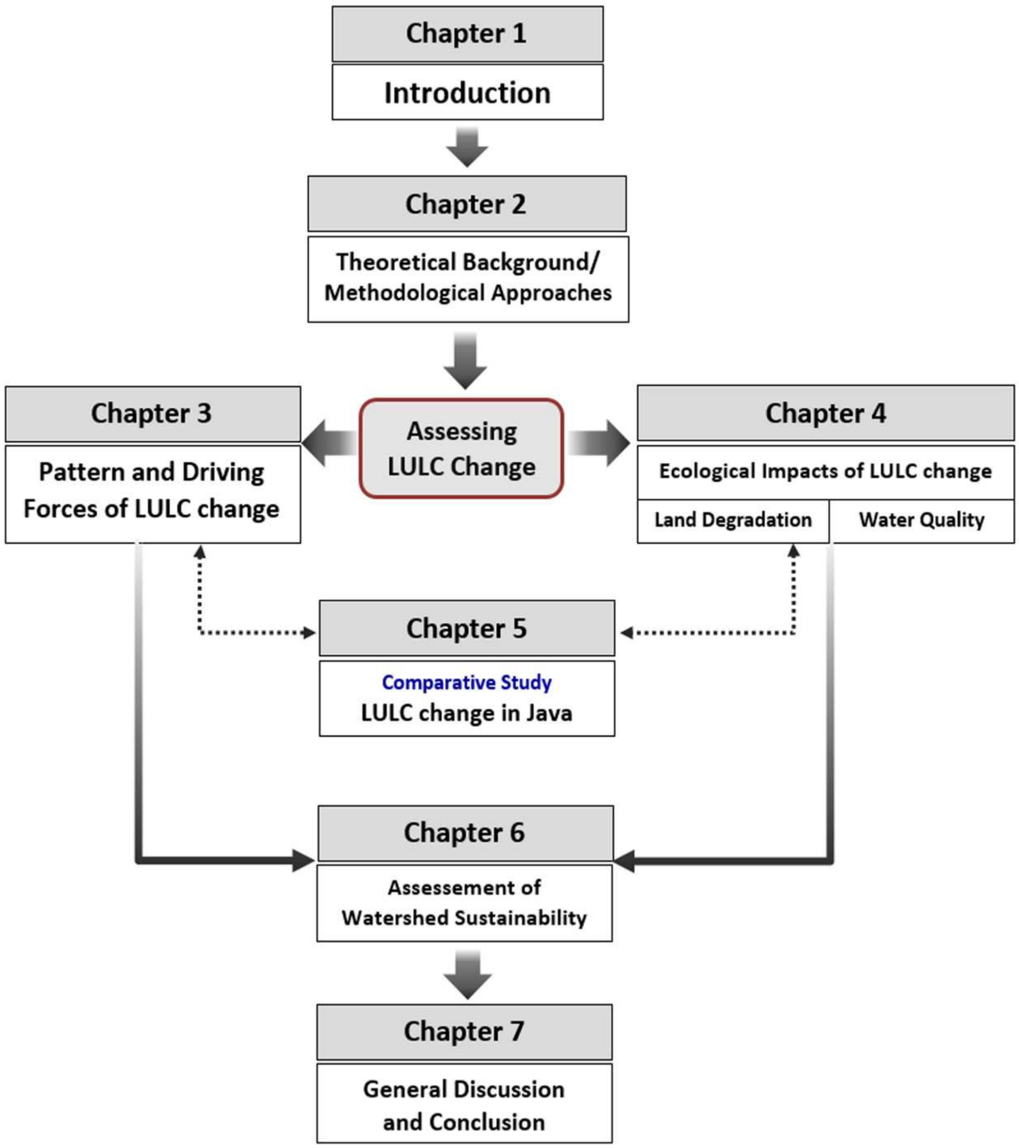


Figure 1. 1 Dissertation structure

Chapter 2

Theoretical background and methodological approaches

2.1 Theoretical background

2.1.1 Theoretical framework of LULC change

2.1.1.1 Defining land, land cover, and land use

Definition and description of land, land cover, and land use vary with the purpose of the application and the context of their use (Turner, 2002) and the concepts of land, land cover, and land use are closely interrelated. Land is any delineable area of the Earths' terrestrial surface involving all attributes of the biosphere immediately above and below this surface (European Commision, 2001). It encompasses the near-surface climate, soils and terrain, surface hydrology and human settlements patterns and physical results of human activities. Land can be considered in two domains, i.e. land in its natural condition, and land that has been modified by human beings to suit a particular use or a range of uses. Land concept involves a variety of functions inluding environmental, economic and social (Hubacek and van de Bergh, 2002). Regarding environmental issues, land acts like soil, filter for clean water and habitat for wild fauna and flora. Additionally, land links climatic, water, and atmospheric systems. On the economic side, land allocates production activities, infrastructure, housing, and also capital assets. On the social level, landowners have social prestige. Land is one of the three traditional production inputs.

It includes terrestrial surface, oceans, and sunlight energy. Land's role changed with time in the economic discipline, which has accounted for its contribution to human well-being as one of land's benefits (Hubacek and van de Bergh, 2002).

The terms land cover and land use are often used interchangeably but their actual meanings are not synonymous. Land cover has been defined by the attributes of the Earth's land surface and immediate subsurface (Lambin et al., 2006), or refers to the physical and biological cover over the surface of the earth, including water, vegetation, bare soil, and/or artificial structures (Ellis, 2010). On the other hand, Land use refers to the intended use or management of the land cover type by human beings (Lambin et al., 2006). Land use has been defined as the purposes for which humans exploit the land cover (Ellis, 2010) or the manner in which human beings utilize the land and its resources (Lambin et al., 2006), with a more complicated term as terms of syndromes of human activities such as agriculture, forestry and building construction that alter land surface processes including biogeochemistry, hydrology and biodiversity (Ellis, 2010). Moreover, the need to distinguish between land use and land cover to account for interactions between socioeconomic and biophysical processes is one source of complexity (Lambin et al., 2006).

Land cover classification is the process of defining land cover and land use classes based on well-defined diagnostic criteria. A classification describes the systematic framework with the names of the classes and the criteria used to distinguish them, and the relationship between classes. Such information is taken from ground surveys or through Remote Sensing (RS). The efforts in creating a land use classification fall into two broad approaches, the functional and the sequential approaches (European Commision, 2001) which are described below:

1. *Functional approach* is defined as the description of land in terms of its socioeconomic purpose and has been defined to be applicable for all land use purposes such as agriculture, forestry, and settlement. As such, functional uses of land can be made at a single point in time or over a shortened period of time.
2. *Sequential approach*, or called the sequence of operations approach, was designed primarily for classifying agricultural lands. The approach defines land use as a series of operations on land, carried out by humans, with the intention to obtain products and/or benefits through using land resources. It requires observation over an extended period of time.

2.1.1.2 Theorizing LULC change and its driving forces

LULC change also known as land change is a general term for the human modification of Earth's terrestrial surface (Ellis, 2010). LULC change is commonly divided into two broad categories: conversion (a change from LULC category to another e.g from forest to grassland) and modification (a change within one LULC category e.g. from rainfed cultivated area to irrigated cultivated area) (European Commision, 2001). Land cover modifications entail the changes that affect the character of the land without changing its overall classification and can either be human induced, for example, tree removal for logging; or have natural origins resulting from, for example, flooding, drought and disease epidemics. Land cover conversion is the complete replacement of one cover type by another such as deforestation to create cropland or pasture.

Change is an intrinsic characteristic of landscape that long term changes linked to phenomena and evolution or short term changes linked to physiological rhytms (Francoise and Boudry, 2003). Comprehension of landscape change requires a rigorous understanding of the underlying processes (Pena et al., 2007) and a full range of methods from the natural and social sciences (Ellis, 2010). The reason why the linkage between land use and land cover change is emphasized is that the environmental impacts of land use change and their contribution to global change are mediated to a considerable extent by land cover change (Briassoulis, 2000, 2008). Thus, their analysis needs the examination of the ways in which land use relates to land cover change at various levels of spatial and temporal detail. Local level land use change may not produce significant local land cover change (and consequently, no significant environmental impact). However, they may accumulate across space and/or over time and produce significant land cover change at higher (e.g. regional, national or global) levels (Briassoulis, 2000, 2008).

The analysis of land use change revolves around two central and interrelated questions: "what drives/causes land use" and "what are the environmental and socioeconomic impacts of land use chage" (Briassoulis, 2008). One of the fundamental theories in the study of land change is the force that observe land change or called "driving force" (Bürgi et al., 2004). However, there are two main categories widely accepted: biophysical and socioeconomic drivers (Briassoulis, 2008). It is generally accepted that there are two main driving forces of land change namely biophysical forces (Lambin et al., 2003) and socioeconomic or anthropogenic drivers (Su et al., 2011). There are also five major types of driving forces of LULC namely socioeconomic, political, technological, natural, and cultural driving forces (Bürgi et al., 2004).

Driving forces of LULC change are well documented and can be also grouped into proximate and underlying factors (Lambin et al., 2001). The proximate causes of land use changes constitute human activities or immediate actions that originate from intended land use and directly affect land cover (Turner et al., 1994). The underlying causes explain the broader context and fundamental forces underpinning these local actions (Lambin and Geist, 2007). As a result, underlying causes also tend to be complex and tend to operate more diffusely, often by altering one or more (Lambin and Geist, 2007).

Some studies disclosed that the relationship between land change and its causative factors is complex and dynamic (Minale, 2013), strongly related to socioeconomic factors (Long et al., 2007) and may occur at various temporal and spatial scales (Reid et al., 2000). As a result of complex interaction between several biophysical and socioeconomic conditions (Reid et al., 2000), it constantly changes in response to the dynamic interaction between underlying drivers (inderect or root) and proximate causes (direct) (Lambin et al., 2003). Generally, physical driving factors are limited, static and easily quantified while anthropogenic factors are diverse andreflect landscape change accurately, however, it is hard to analyse them quantitatively (Su et al., 2011). The complexity of patterns, drivers, and impacts of LULC change has so far impeded the development of an integrated theory of land change (Lambin et al., 2006). Futhermore, land change science (LCS) has now emerged as a central component of global environmental and sustainability research (Turner et al., 2007).

Studies of land use change should conceptualise the interactions among the driving forces of land use change, their mitigating procedures and human behaviour and organisation (Bürgi et al., 2004). Human actions take place in response to the socio-cultural and physical environment and are aimed at increasing their economic and socio-cultural well being (Lambin et al., 2006). Land use patterns are a consequence of these human actions and should not be viewed independently of the driving forces underlying the motivation for production and consumption (Briassoulis, 2008).

Several theories of land use change intend to describe the structure of the change in the use of land from one type to another and explain why these changes occur, what causes these changes, what are the mechanisms of changes. The “what” and the “why” of land use change are closely related although existing theories rarely address both (Briassoulis, 2000). The majority of theories of land use change lay in the more general theoretical framework of discipline studying economic, environmental and spatial change (transformation). Theories of land use change can be classified into three main categories (Briassoulis, 2008): the urban and regional economics theories, the sociological (political economy) theories, and the nature-society (human-nature) theories, which address mainly the human role in causing global environmental change. Some theories and models have been conceived simultaneously in which case the terms "theory" and "model" are used interchangeably to denote a set of theoretical and operational statements about reality (such as von Thunen’s and Alonso’s theories and models) (Briassoulis, 2008).

However, the majority of the literatures on LCS is in land use patterns either by converting the natural land into human use or changing management practices of human-dominated ecosystems (Lepers et al., 2005). As result, the majority of theories of land use change can be classified into three main categories: the urban and regional economics theories, the sociological (and political economy) theories, and the nature-society (or human-nature) theories, which address mainly the human role in causing global environmental change (Briassoulis, 2000). LULC change has become a central component in current strategies for managing natural resources and monitoring environmental changes.

2.1.1.3 LULC analysis using satellite remote sensing

Remote sensed data provides the capability to monitor a wide range of landscape biophysical properties to management and policy, where information is needed in the past, present and future (Aspinall, 2008; Jensen, 2004; Lilleesand et al., 2004). There exist several imagery satellites with very different imaging characteristics, e.g. Landsat series, Spot, Aster, Ikonos, Quick Bird, Geoeye, etc. Landsat series of satellites is a primary environmental data source and is most commonly used in local and regional level for many research purposes, e.g. water quality (Hadjimitsis and Clayton, 2009; Wilson, 2000), soil erosion (Beskow et al., 2009; Xu et al., 2011), land degradation (Symeonakis et al., 2007), biodiversity assessment (Baan et al., 2012; Sambou et al., 2010).

The image processing can broadly be categorized into: pre-processing, image classification or segmentation, post processing and evaluation (Jensen, 2004). The most common pre-processing techniques in RS data include radiometric and geometric correction, radiometric enhancement, spatial enhancement, spectral enhancement, and fourier analysis (Jensen, 2004; Lilleesand et al., 2004). Radiometric correction addresses variations in the pixel intensities (DNs) that are not caused by the object or scene being scanned. This correction aimed to minimise variation due to varying solar zenith angles and incident solar radiation. Several algorithms have been developed to radiometric correction (Jensen, 2004). LULC mapping and subsequent quantitative change detection required geometric registration between TM and ETM scenes, and radiometric rectification to adjust for differences in atmospheric conditions, viewing geometry and sensor noise and response (Lilleesand et al., 2004). One of the pre-processing of satellite image is making geometric corrections before data base creation. Geometric correction addresses errors in the relative positions of pixels. It is undertaken to avoid geometric distortions from a distorted image.

There are many different approaches to classifying remotely sensed data. Image classification is the process of categorizing the pixels of an image into a specific number of individual classes based on set criteria (European Commision, 2001). Categorization is primarily based on the spectral patterns and radiance measurements obtained in the various bands of the individual pixels in an image (Lilleesand et al., 2004). However, in common image classification, there are two main classification namely unsupervised and supervised classification (Jensen, 2004). In unsupervised classification, an algorithm is chosen that will take a remotely sensed data set and find a pre-specified number of statistical clusters in multi-spectral or hyper-spectral space (Ismail et al., 2009). The main purposed of unsupervised classification is to produce spectral groupings based on certain spectral similarities.

Supervised classification, however, does require prior knowledge of the ground cover in the study site. The supervised approach is preferred by most researchers because it generally gives more accurate class definitions and higher accuracy than the unsupervised classification (Hassan and Elhag, 2013; Ismail et al., 2009; Prasetyo et al., 2009). Once trained, the algorithm can then be applied to the entire image and a final classification image is obtained. Supervised classification involves applying a training process closely controlled by the analyst who must have good experience in the field (area of interest), because in this method the operator defines the spectral characteristics of the classes by identifying sample areas (training areas). The training samples (pixel representing known locations of the area being classified) are then used to classify the remainder of the images (Hassan and Elhag, 2013; Jensen, 2004; Lilleesand et al., 2004).

Both the supervised and unsupervised classifications use the services of a classifier algorithm of which the maximum likelihood is the most popular (Lilleesand et al., 2004). Maximum likelihood is actually the probability that a pixel belonging to specific classes. It is a statistical decision rule that examines the probability function of a pixel for each of the classes, and assigns the pixel to the class with the highest probability and is perhaps the most widely used classification methods. It is one of the most popular methods of classification in RS and usually provides the highest classification accuracies (Ismail et al., 2009; Perumal and Bhaskaran, 2010).

Practically, the supervised classification approach will select groups of training pixels that are representative for the six land cover units. This training data set forms the basis for classification of the total satellite image, by using the maximum likelihood classifier (MLC). In unsupervised classification approach, isodata clustering is commonly used, in which clusters of pixels based on their similarities in spectral information are automatically classified into the desired number of LULC categories.

Accuracy assessment is an essential and most crucial part of studying image classification and thus LULC change detection in order to understand and estimate the changes accurately. It is important to be able to derive accuracy for individual classification if the resulting data are to be useful in change detection analysis (Ismail et al., 2009; Lilleesand et al., 2004; Shewangizaw and Michael, 2010). This needs for accessing accuracy of spatial data derived from RS techniques and used in Geographic Information System (GIS) analysis has been recognized as a critical component of many projects (Congalton, 1991). If information derived from RS data is to be used in some decision-making process, then it is critical that some measure of its quality be known (Congalton, 1991). The most common accuracy assessment elements include overall accuracy, producer's accuracy, user's accuracy and kappa coefficien (Jensen, 2004). One of the most common methods of expressing classification accuracy is the preparation of a classification error matrix (Lilleesand et al., 2004). An error matrix is an array of numbers set in rows and columns that express the number of sample units assigned to a particular category in one classification relative to the number of sample units assigned to a particular category in another classification (Congalton, 1991; Ismail and Jusoff, 2008). The error matrices compare, on a category by category basis, the relationship between known reference data and the corresponding results of the automated classification. The matrix is able to identify both omission and commission errors in the classification as well as the overall, producer's and user's accuracy.

2.1.1.4 Ecological impacts of LULC change

LULC significantly affects key ecological functions and the critical issue of global environmental change (de Chazal and Rounsevell, 2009) and its changes are cumulatively a major driver of global change (Turner et al., 2007). It is therefore a serious issue in sustainable development studies and in the integrated assessment of environmental problems (Veen and Otter, 2001).

LULC change influences carbon fluxes and greenhouse gas (GHG) emissions which directly alter atmospheric composition and radiative forcing properties (Marland et al., 2003; WMO, 2005). Changes in land surface can also change the radiation balance by altering the Earth's surface albedo. In addition, changes in land surface can alter the fluxes of sensible and latent heat to the atmosphere and thus the distribution of energy within the climate system (WMO, 2005). Land surface is an important part of the climate system. The interaction between land surface and the atmosphere involves multiple processes and feedbacks, all of which may vary simultaneously. It is frequently stressed that the changes of vegetation type can modify the characteristics of the regional atmospheric circulation and the large-scale external moisture fluxes. So that changes in surface energy budgets resulting from land surface change can have a profound influence on the Earth's climate (WMO, 2005).

A much broader range of impacts of land-use/cover change on ecosystem goods and services were further identified (DeFries and Bounoua, 2004), especially in tropical regions (Lambin et al., 2003). Furthermore, LULC change is critical issue due to its great influence on landscape patterns (Feng et al., 2011), land degradation (Symeonakis et al., 2007), biodiversity loss (Baan et al., 2012), water quality (Uriarte et al., 2011), eco-hydrological effects (Fu et al., 2005), and human life (Maitima et al., 2010). It can be stated that LULC change occurs in local places, with real-world social and economic benefits, while potentially causing ecological degradation across local, regional, and global scales (Foley et al., 2005).

2.1.1.5 LULC studies around tropical countries

Concerning LULC change and its ecological impacts in humid tropical countries, many research have been conducted as in Latin American countries such as Brazil, Bolivia, and Paraguay (Hansen et al., 2008), tropical African countries such as Kenya (Odira et al., 2010), and South Asian countries (Sodhi et al., 2010) *e.g* Indonesia and Papua New Guinea (Ningal et al., 2008)). In Asia region, Southeast Asia has experienced one of the highest rates of deforestation in the tropics due to extreme LULC change, which are expected to result in species declines and extinctions (Sodhi et al., 2010). Among tropical regions, Indonesia exemplifies this critical situation and experiences one of the highest rates of deforestation due to land change such as agricultural expansion, deforestation and habitat fragmentation. The predominance of Indonesia in humid tropical forest clearing accounts for 12.8% of the total forest loss and the loss of humid tropical forest cover results in a concomitant loss in biodiversity richness (Hansen et al., 2008).

2.1.2 Theoretical framework of watershed management

2.1.2.1 Defining watershed

The term "watershed" describes an area of land that drains downslope to the lowest point where the water moves by means of a network of drainage pathways that may be underground or on the surface (Watershed Professional Network, 1999). It can be defined as the area that drains to a common outlet. It is the basic building block for land and water planning (Darghouth et al., 2008). The characteristics of the water flow and its relationship to the watershed are a product of interactions between land and water (geology, slope, rainfall pattern, soils, and biota) and its use and management. Hydrologically, watershed is an area from which the runoff flows to a common point on the drainage system. Its boundaries will follow the major ridge-line around the channels and meet at the bottom where the water flows out of the watershed, commonly referred to as the mouth of the stream or river (Watershed Professional Network, 1999). Every stream, tributary, or river has an associated watershed, and small watersheds aggregate together to become larger watersheds. It includes all land areas extending from the ridge down to the stream for which water is collected (Cruz, 1999). Watershed is a terrestrial ecosystem consisting of intricately interacting biotic and abiotic components (Cruz, 1999). A watershed is a complex ecosystem with interacting natural components (de Guzman and Reyes, 2003). Therefore, watershed can be classified into an upland watershed, a lowland watershed, agricultural watershed, a forested watershed and an urban watershed (Cruz, 1999). The watershed is the logical unit for coordinated land-use planning and management and effective and sustainable resource and environmental management (UN-ESCAP, 1997). However, watershed in hydrologic equilibrium should be the goal for sustainability of water resources and for the health, safety, and welfare of humans in general (de Barry, 2004).

2.1.2.2 Watershed management: unit, history, issues and apporaches

Criteria for selecting watershed size also depend on the objectives of the development and terrain slope (Wani et al., 2008). Watershed is not simply the hydrological unit but also socio-political-ecological entity which plays crucial role in determining food, social, and economical security and provides life support services to rural people (Wani et al., 2008). Darghouth *et al.*, (2008) suggests a possible classification of some characteristics of watersheds at different levels (Table 2.1).

Tabel 2.1 Watershed management unit and its characteristics

Watershed Management Unit	Area (km^2)	Influence of Impervius Cover	Primary Planning Authority	Management Focus
Micro-watershed	0.05 – 0.50	Very strong	Property owner (local)	Best management practice and site design
Sub-watershed	1.0 – 10.0	Strong	Local government	Stream classification and management
Watershed	10.0 – 100.0	Moderate	Local or multiple government	Watershed based zoning
Sub-basin	100 – 1,000	Weak	Local, regional, or state	Sub-basin planning
Basin	> 1,000	Very weak	State, multi state, federal	Basin planning

Adopted from Darghouth *et al.*, (2008)

The first generation of watershed management projects in developing countries in the 1970s and 1980s applied a soil and water planning approach to watersheds, which emphasized engineering works aimed at specific on-site and downstream physical outcomes (Darghouth et al., 2008). The watershed management approach became prominent in developing countries in the 1970s and 1980s when the problems of watershed degradation first became apparent (FAO, 2006). From the 1990s, watershed management programs supported by the international community in developing countries typically targeted livelihood improvements and poverty reduction objectives in addition to resource conservation (Darghouth et al., 2008). However, in the present context, watershed management is not only for managing or conserving natural resources in a holistic manner, but also to involve local people for betterment of their lives (Achouri, 2003). Thus, modern watershed management is more people oriented and process based, unlike many of the programs in the past, which were physically target oriented (Kerr, 2007; Naiman et al., 1997; Tyler and Fajber, 2009).

Degradation of watersheds in recent decades has brought the long-term reduction of the quantity and quality of land and water resources (Darghouth et al., 2008). Degradation of natural resources is considered to be the greatest constraint to sustainable agricultural development in most developing countries (Achouri, 2003). During the last few decades, degraded watersheds have posed serious problems to environment and people, both upstream and downstream and 43 percent of the agricultural lands in eight South Asian countries were affected by some form of degradation (Tennyson, 2003). Degradation results from a range of natural and anthropogenic factors, including natural soil erosion, changes in farming systems, overgrazing, deforestation, and pollution

(Darghouth et al., 2008). As results, depletion of soil productivity, sedimentation of water courses, reservoirs and coasts, increased runoff and flash flooding, reduced infiltration to groundwater, and water quality deterioration are among the main negative impacts of watershed deterioration. These impacts can have profound effects on public and ecosystem health, the economy, and livelihoods of the population, both in the already poor upland areas and in the downstream areas (Darghouth et al., 2008). The combination of environmental costs and socioeconomic impacts has led to the development of watershed management approaches. To overcome the watershed degradation problems many developing countries have practiced different watershed management approaches from top-down and sectoral to bottom-up, participatory and integrated types (Tiwari et al., 2008).

Watershed management is a landscape-based strategy that aims to implement natural resource management systems for improving livelihoods and promoting beneficial conservation, sustainable use, and management of natural resources (Chisholm and Woldehanna, 2012). Watershed management refers to managing hydrological relationships in a watershed, which may involve protecting certain resources from degradation rather than making physical investments in their productivity (Kerr, 2007). Watershed management is complicated by the fact that watersheds rarely correspond to human-defined boundaries (Sharma and Scott, 2005). The key characteristics of a watershed that drive management approaches are the need for integrated land and water management, the causal link between upstream land and water use and downstream impacts, the typical nexus in upland areas between resource depletion and poverty, and the multiplicity of stakeholders (Darghouth et al., 2008).

Table 2.2 Different aspects of watershed management

in developing and developed countries

Activities	Developing countries	Developed countries
Output	Farm production	Water yield
Focus	Livelihoods of the communities	Water quality
Program	Community based socioeconomic activities	More on natural resource management
Approach	Applied science and participatory approach	Science based
Action	People oriented	Natural resource oriented

Adopted from Tiwari *et al* (2008)

As a unit for natural resource managaement (Bruneau, 2005), watershed management provides the basis for dealing more effectively in an integrative fashion with the biophysical and socioeconomic aspects of natural resource and environmental problems (WGWMD, 1988). Tiwari *et al* (2002) review and distict the objectives of watershed management in developing and advanced countries (Table 2.2). In case of developing countries, watershed management is more focused on local people's requirements and sustainable livelihoods, whereas in advanced countries, it is focused on water quality and supply.

2.1.3 The concept of sustainability and sustainability assessment

2.1.3.1 Defining Sustainability

Sustainability is a dynamic concept (Bossel, 1999) and it has only been recognised formally as a concept within the last half-century, with developments in contributions towards understanding the topic accelerating mainly from the late 1970s (Tuazon et al., 2013). There are around 140 alternatives and variously-modified definitions of 'sustainable development' emerged. Currently, it has been estimated that some 300 definitions of 'sustainability' exist broadly within the domain of environmental management and the associated disciplines which link with it, either directly or indirectly (Johnston et al., 2007). For example, sustainabilty can be viewed from many aspects, i.e. technical sustainability (balanced demand and supply, no mining); financial sustainability (cost recovery); social sustainability (stability of population, stability of demand, willingness to pay); economic sustainability (sustaining economic development or welfare and production); institutional sustainability (capacity to plan, manage and operate the system); and Environmental sustainability (no long-term negative or irreversible effects) (Saleh and Jayyousi, 2008). Although no consensus on its emerged definition, sustainability has developed into a new paradigm (Owens, 2008).

Sustainability should be distinguished from sustainable development. Sustainability is about respecting the processes at work in our ecosystem so as to ensure, or at least prolong, our survival as a species, and concerns our level of connectedness with future generations. One of the reasons for the present status of sustainability or sustainable development is that it comprises such a wide range of topics, scales and disciplines. (Klapka, 2007). Sustainability reveals that the subject of sustainability deals with environmental and ecological issues (Shaharir, 2011) and cultural aspects (Jenkins, 2003). Sustainability appears to be a more complex and thus more difficult to handle concept that is connected with adaptive management, biodiversity, ecological integrity and resilience rather than with policy, elitism or an accent on economy (Klapka, 2007). By contrast sustainable development is about pragmatics, or ways in which we can organise ourselves politically, whether upon local, regional, national or global levels, so as to engage in habits of living which respect Sustainability (Stallworthy, 2002). Sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). Although the pillars of sustainability should theoretically be in balance, actually the economic component is being accentuated in understanding of the sustainability concept (Klapka, 2007).

Sustainability concept also corresponds to ecocentric (ecologically centered) and anthropocentric (human-centered) positions in environmental ethics (Jenkins, 2003). The ecocentric view requires that moral decisions take into account the good of ecological integrity for its own sake, as opposed to exclusively considering human interests; on the other hand, a strong sustainability view could be held from an anthropocentric perspective by arguing that human systems depend on rich biodiversity or that human dignity requires access to natural beauty (Jenkins, 2003). Therefore, Mebratu (1998) point out the comparative analysis of the academic views of sustainability (Table 2.3)

Table 2.3 Comparative analysis of the academic views of sustainability

Academic Discipline	Epistemological Orientation	Source of Environ. Crisis	Solutions Epicenter	Instruments
Environmental economics	Economic reductionism	Uncervaluing of ecological goods	Internationalization of externatilites	Market instrument
Deep Ecology	Ecological Reductionism	Human domination over nature	Reverence and respect for nature	Biocentric egalitariasim
Social Ecology	Reductionist-holicstic	Domination of people and nature	Co-evolution nature and humanity	Rethingking of social hierarchy

Adopted from Mebratu (1998)

Practically, sustainability may exist in varying degrees, from weak to moderate to strong, depending on the degree of substitution of capital. To balance economic, environmental, and social factors, different types of sustainability may be appropriate (The Miiskatis Institute, 2004). Weak sustainability looks at maintaining the total capital intact, implying that different forms of capital are substitutes, at least within the boundaries of current levels of economic activity and resource endowments. Moderate sustainability requires that in addition to maintaining the total level of capital intact, some concern be given to the composition of that capital. Strong sustainability requires maintaining individual types of capital intact and it holds that should be absolutely protected (Jenkins, 2003). By now it is evident that theories of sustainability have become too complex to organize with dualistic terms like strong and weak or ecocentric and anthropocentric. These models—economic, ecological, and political—are not mutually exclusive and often integrate complementary strengths of the others. Distinguishing them, however, helps make sense of alternative concepts of sustainability (Jenkins, 2003).

2.1.3.2 Concept and method for sustainability assessment

In the context of the principle of sustainable development, it is not surprising that Sustainability Assessment (SA) is becoming more common as a decision-making tool intended to anticipate the sustainability implications of proposed plans, actions, and policies (Bond and Morrison-Saounders, 2010). SA is being increasingly viewed as an important tool to aid in the shift towards sustainability (Pope et al., 2004). It can be defined as an evaluation and optimization instrument that is aimed at strengthening of sustainable development in decision making process across all areas (ARE, 2004). The purpose of sustainability assessment is to provide decision-makers with an evaluation of global to local integrated nature–society systems in short- and long-term perspectives in order to assist them to determine which actions should or should not be taken in an attempt to make society sustainable (Singh et al., 2009). After almost 20 years of debate there seems to be a consensus that sustainability assessments ought to integrate economic, environmental, social and increasingly institutional issues as well as to consider their interdependencies; consider the consequences of present actions well into the future; acknowledge the existence of uncertainties concerningthe result of our present actions and act with aprecautionary bias; engage the public; and include equity considerations (Gasparatos et al., 2008).

Many frameworks have been developed over the last two decades so as to try to measure the impact of human activity on the society and the environment (Sood and Ritter, 2011). Four major international models have been developed to measure sustainability namely "Framework for the Development of Environmental Statistics (FDES) developed by the United Nations Statistical Office, Pressure-State-Response

(PSR) framework developed by the Organization for Economic Cooperation and Development (OECD), The Driving Force-State-Response (DSR) framework developed by the Commission on Sustainable Development., and the Driving Force-Pressure-State-Impact-Response (DPSIR) framework developed by the European Environmental Agency (EEA) and the Statistical Office of the European Communities (Eurostat). (Adinyira et al., 2007; Bond and Morrison-Saounders, 2010; Gibson et al., 2005; Morison-Saunders and Therivel, 2006).

The PSR framework is based on the following concept of causality: human activities exert pressures on the environment and change its quality and the quantity of natural resources (the state), society responds to these changes through environmental, general economic and sectored policies (the societal response) (Singh et al., 2009). The PSR framework provides a useful way of organizing information about the elements of sustainability. According to this framework, the condition of society can be seen as depending on a number of states - for example, the quantity of built capital, the size and quality of natural resource stocks, the state of knowledge, the quality of the environment, the health of environmental systems, and the performance of social institutions in meeting and coordinating human needs (Toman et al., 1998). Human activities produce pressures on various states - some potentially detrimental, like releases of pollutants; some ameliorative or positive, like investment in environmental restoration and human capital; and some more neutral or ambiguous, like depletion of natural resource stocks. These pressures in turn cause responses in the states (environmental degradation or improvement). This framework draws attention to the assessment of a variety of changes in stocks and other flows that affect a society's well-being. (Toman et al., 1998).

Since sustainable development became the catchword in international discussions, several approaches to sustainability assessment have been developed (Becker, 1997). Singh *et al* (2009) overviewed 41 sustainability Indices and grouped into several major indices, i.e. Innovation, knowledge and technology indices, Development indices, Market and Economy based indices, Ecosystem based indices, Sustainability Performance Index (SPI), Eco-Index Methodology (EIM), Living Planet Index (LPI), and Ecological Footprint (EF), Composite sustainability performance indices, Investment, rating and asset management indices, Product based sustainability indices, Sustainability indices for cities, Environmental indices for policies, nations and regions, Environmental Sustainability Index (ESI), Environmental Quality Index (EQI), Index of Environmental Friendliness (IEF), Environmental Performance Index (EPI), Environmental Vulnerability Index (EVI), Environmental Indices for industries, Energy based indices, and Social and Quality life based indices. Although there are various international efforts onmeasuring sustainability, only few of them have an integral approach taking into account environmental, economic and social aspects. In most cases the focus is on one of the three aspects.(Singh et al., 2009; Böhringer and Jochem, 2008). All assessments relflect the need to mobilize scientific, economic, ecological and social tools to address some of the most important environmental issues (Harris, 2002).

Environmental sustainability assessment is a rapidly growing field where measures of sustainability are used within an assessment framework to evaluate and compare alternative actions (Hester and Little, 2013). Increased awareness of the broad dimensions of environmental sustainability as applied to water management should encourage integration of existing approaches into a unified assessment framework appropriate for watersheds (Hester and Little, 2013).

Yet the watershed is one of the most fundamental units of analysis for water resources, the watershed sustainability must be quantified at that level to be useful in decision-making processes that occur at similar scales. The importance of the watershed scale to sustainability assessment has been acknowledged in only a few recent studies, and only limited papers have reviewed the available measures (Harris, 2002). Assessment of watershed sustainability should give a detailed evaluation of the specific processes, influences, and problems in a watershed so that a plan of action to preserve the watershed can be developed and how well a watershed function is working (de Barry, 2004). This process includes steps for identifying issues, examining the history of the watershed, describing its features, and evaluating various resources within the watershed (Watershed Professional Network, 1999). Watershed assessment involves the analysis of data from many different ecological areas such as sediment yield, impervious surface area, and amount of riparian vegetation as well as community needs or concerns and private/commercial water demands (Randhir, 2007). Watershed assessment can be used to determine the changes to ecosystem health and productivity associated with land management practices.

In summary, the section discusses about several relevant subjects for the study of LULC change toward sustainability of humid tropical watersheds can be briefly described as follows (Figure 2.1)

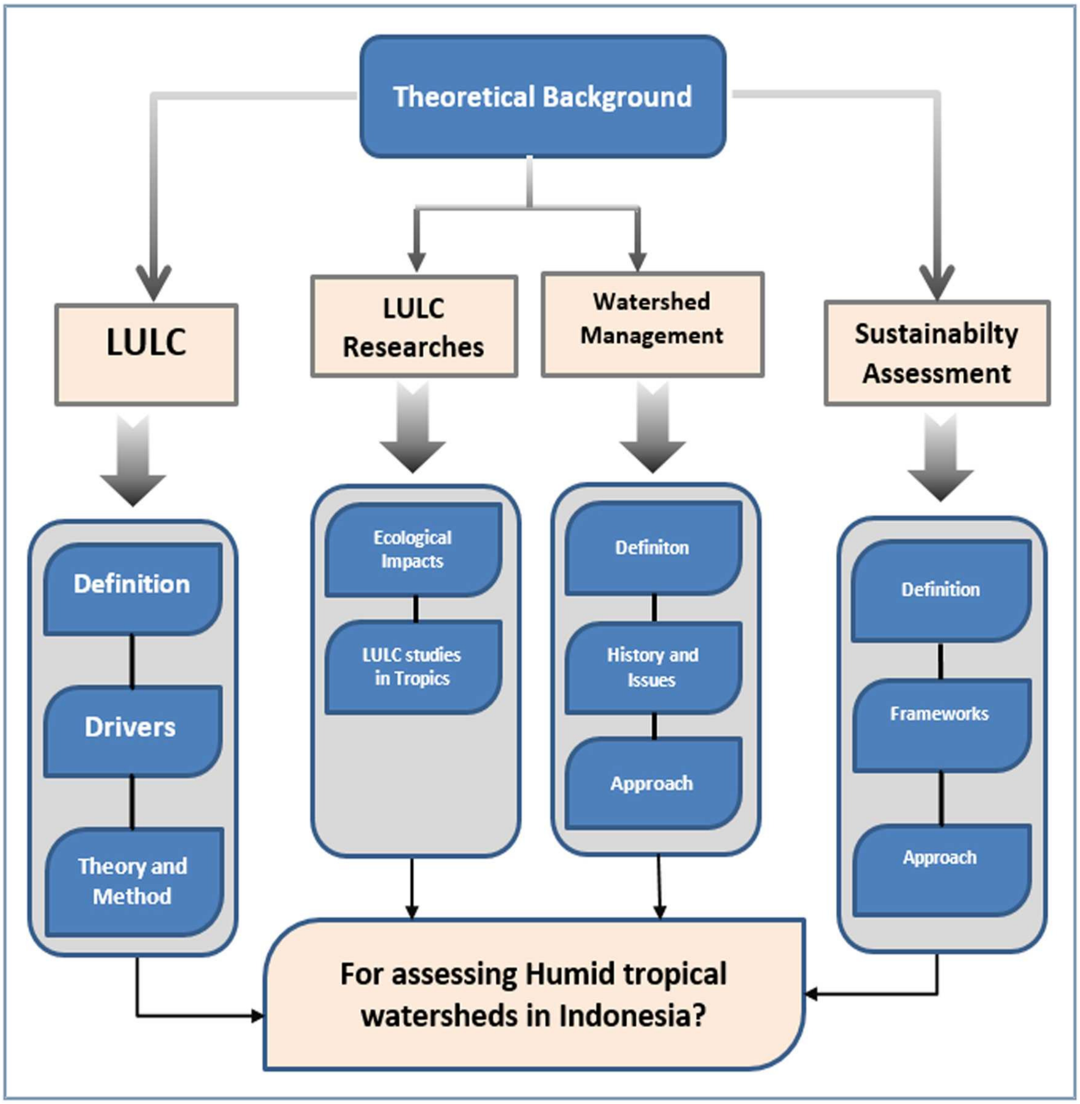


Figure 2.1. Summary of theoretical background

2.2 General description of watershed management in Indonesia

2.2.1 Formal history of watershed management in Indonesia

In Indonesia, information on a formal history of spatial planning and watershed management has important role for further understanding and future development, as summarized in Figure 2.2. Before 1990s, the spatial planning system referred the Act No. 5/1990 about Agrarian Rules. In response to the growing need for coordinating the management of natural resources, then the first spatial planning law had been issued through Law No. 24/1992 about Spatial Planning. In accordance with the new decentralization era which has been implemented since 2000, then finally the government released the new the Spatial Planning Law No. 26/2007. On the other hand, there are many differents regulations in order to manage watershed or river basin. The first regulation for river management was Act No. 11/1974 about Irigation then followed by the first formal regulation on Rivers through regulation No. 35/1997. Also, in response the regional autonomy implementation, the government released regulation on water resource (Act No. 7/2004) and new regulation on Rivers (No. 38/2011). Finally, the first regulation of watershed management has been issued through Act. No. 37/2012 while the formal watershed management began during 1970s in response to massive flooding in Solo City, Central Java (Anwar, 2003).

Unfortunately, the implementation of the regulations does not work well because of some problems such as coordination system and data management. For example, spatial planning and river management are controlled by Ministry of Public Works while watershed managemet is controlled by Ministry of Foresty.

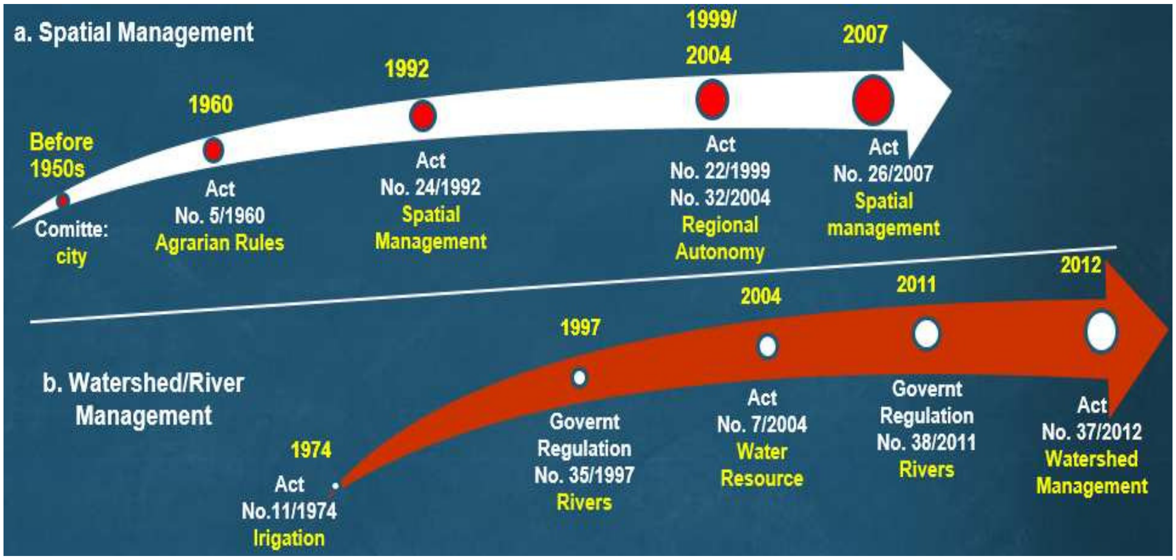


Figure 2.2. Summary of formal regulation in Indonesia for

a) spatial management and b) watershed/river management

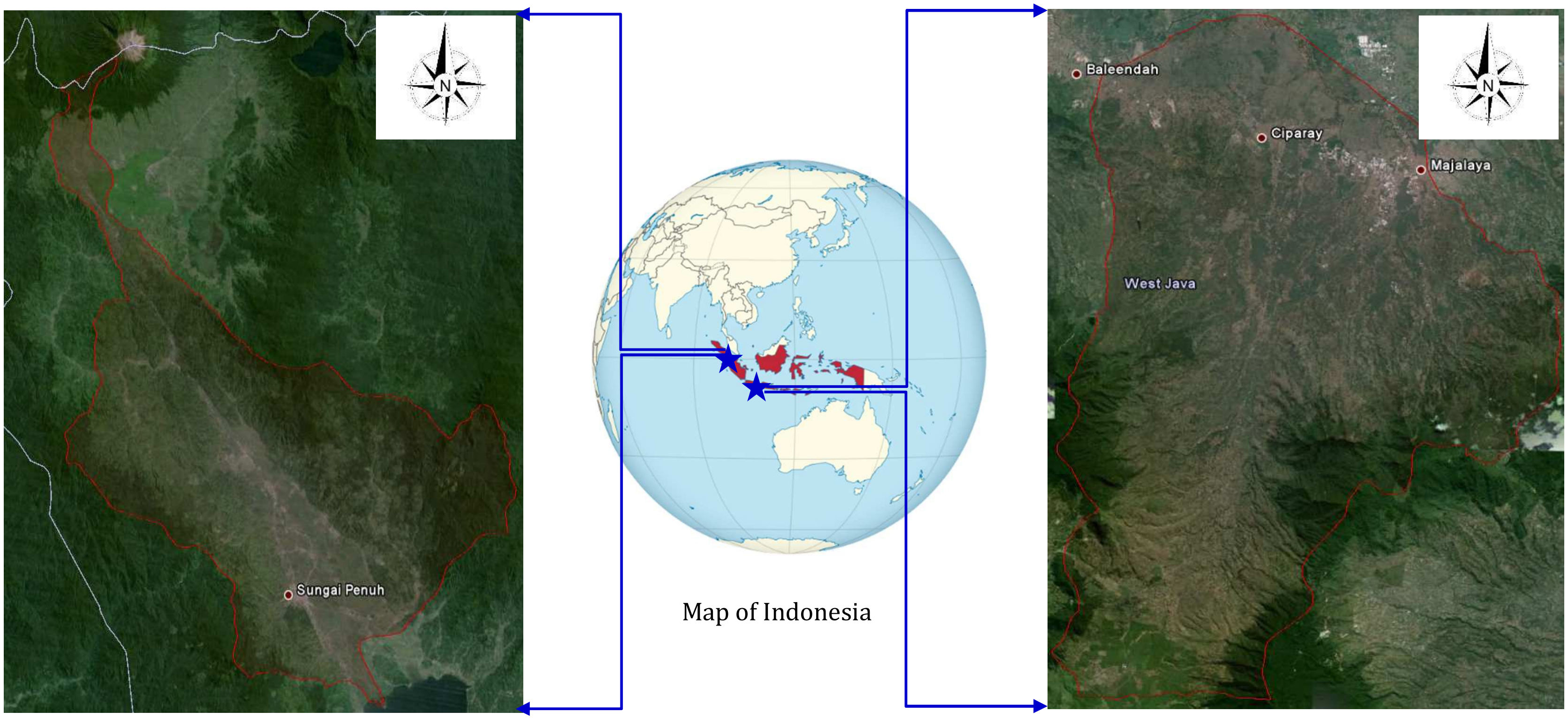
Regarding data availability, there are only 60% of 458 watersheds have complete data and mostly those in Java and Sumatera Islands (Anwar, 2003). Now, about 470 watersheds in Indonesia which are mostly degraded condition (Ministry of Forestry of Indonesia, 2004, 2010) have been carried out by the 31 regional watershed management centres (BPDAS). The formal history above explains about the complexity of formal land and watershed management and it is not an easy task to achieve sustainability for both land and watershed.

2.2.2 General description of the two humid tropical watersheds

Batang Merao watershed, a representative of the little known land change in humid tropical region in Indonesia, is one of the key regions of LULC research and plays an important role in maintaining the conservation function of Kerinci Seblat National Parks and socioeconomic functions of Jambi Province, Indonesia. Since the implementation of regional autonomy started in Indonesia in 2000, land use has rapidly changed and deforestation has also dramatically increased.

Cirasea sub-watershed, was also selected for this research mainly because it is one of the most important sub watersheds of Citarum watershed, a main source of water and protected area in West Java. Cirasea sub-watershed has a prominent role as a conservation area and buffer zone of ecosystem in relation to other regions. The existence of Cirasea sub-watershed as a planning unit is important for regional development in the upland Citarum watershed. One of the main problems in Cirasea sub-watershed is land degradation that can disturb the sustainability of conservation and cultivation functions. The risk impact of land degradation in Cirasea sub-watershed will affect downstream areas such as Bandung city and Karawang regency. In addition, it had undergone substantial land use and land cover change and it was subject to high population pressure.

The size of Batang Merao watershed in Sumatera island is 678.745 Km^2 and Cirasea sub-watershed in Java island is 344.581 Km. Unfortunately, there is no formal regulation or scientific references in Indonesia mention about detail information on watershed typologies or classification based on size criterion. The map of satellite image of the two selected watersheds is shown in the following Figure 2.3:



a) Batang Merao watershed, Sumatera

b) Cirasea sub-watershed, Java

Figure 2.3. Map of satellite images of the two selected watersheds:

a) Batang Merao watershed, and b) Cirasea sub-watershed

2.3 Methodological approaches

2.3.1 Scales of unit analysis

Issues of scale have tested the minds of hydrologists in the study of watershed and river basin (Wallace, 2003) that the difficulty of scaling tasks is reflected in the fact that the key challenge is to be able to predict hydrological behaviour at one scale using information gathered at another scale. Since hydrological science has been inherently multi-disciplinary (Sidle, 2000), it is well placed to act as means of integrating with other disciplines such as forestry, agriculture and landscape ecology.

In the context of watershed management, watershed is generally considered as useful unit of analysis and action because of several physical (natural system, multiple scales, ideal for process studies, integrated framework, assist in addressing complexity) and social (decision-making tool, social organization, upstream and downstream links) characteristics (Bruneau, 2005). In a good watershed management, the linkages of watershed, people, and resource dynamics are connected across multiple scales, and yet there are also dynamics unique to each scale both biophysically and socioeconomically (Bruneau, 2005; Darghouth et al., 2008; FAO, 2006; Sidle, 2000).

The quantitative data required for the calculation of the Hydrology, Environment, Life and Policy (HELP) indicators are available in statistics of Kerinci Regency and Jambi Province, and includes information such as the sub regency and village populations, Human Development Index (HDI) values, and the amount of natural vegetation areas for our study period were acquired from the Regional Develepment Planning Board of Kerinci Regency.

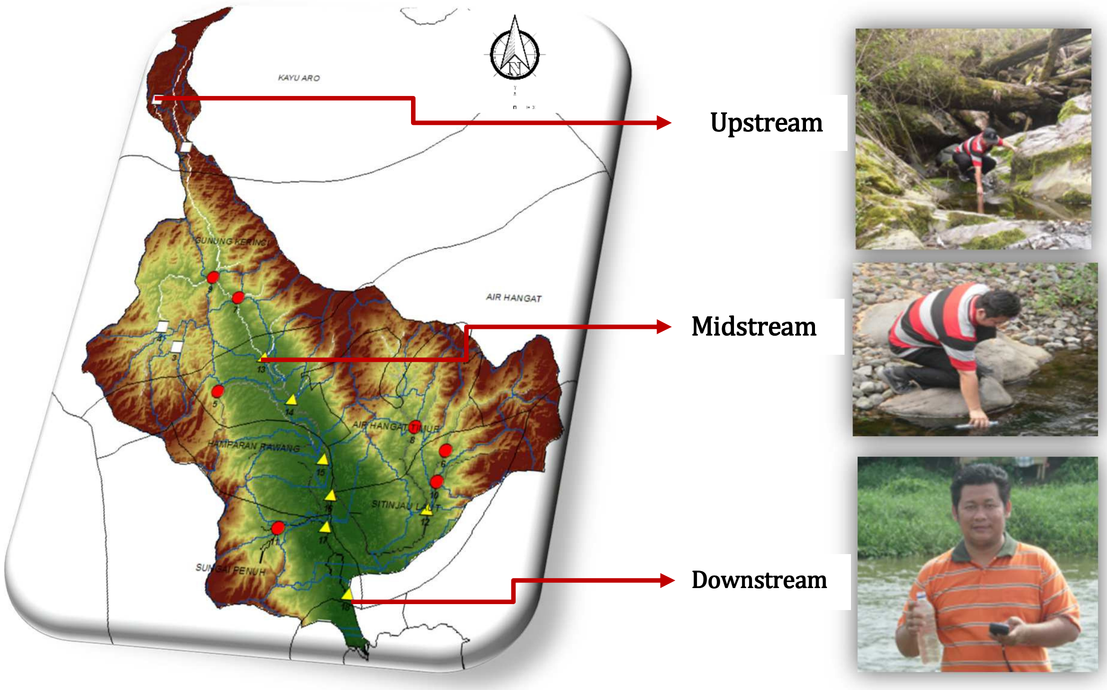


Figure 2.4 Sampling Distribution of water quality in Batang Merao Watershed

For land use land cover, remote sensed data were used as they provide the capability to monitor a wide range of landscape properties for better management and policy. Satellite-based remotely sensed data is commonly recorded in digital form as a grid of cells or pixels. For this purpose, Landsat image ETM data (path 126/row 61) which each pixel represents a 30 m x 30 m ground area, downloaded from the USGS Earth Resource Observation System were used in this study.

Finally, for water quality data, water samples were collected from 15 stations or catchments within Batang Merao Watershed (Figure 2.4). Most of these stations distribute in the upper-middle-downstream area of Batang Merao Watershed. The primary data were collected from field survey on September 20, 2011 while the secondary data for the year 2006 and 2011 were obtained from the Environmental Management Agency of Jambi Province. Also, the secondary data of water availability (W_a) were retreived from the Environmental Management Agency of Jambi Province for the year of 2006 and 2011.

2.3.2 Methods for LULC change analysis

a. Extraction of the study area

Extraction of the watershed through the use of the digital ancillary data sets from the formal watershed boundary from the Center of Batang Hari Watershed and Forestry office of Bandung Regency. In order to sampling the water quality, the use of the digital elevation model (DEM) available from the sensor data SRTM in 90m spatial resolution, in addition to the DEM data from ASTER in 30m spatial resolution. Data was imported to the ArcGIS 10.1 program using the following steps: Export raster data (raw data) to grid-format; ArcToolBox/Spatial Analyst Tools/Hydrology; Conversation Tools (from raster – Watershed-/Raster to polygon); and Analysis Tools: (Extract/Clip). Throughout the proposed results, the spatial distribution layer of the natural borders of river-basin was obtained from the SRTM-data (Figure 2.4 is also a result of this step).

b. Pre-processing of the satelite data

There are a variety of preprocessing procedures that could be applied on satellite data: finding and replacement of damaging lines of pixels; geographical registration of image and geometric rectification; radiometric calibration and atmospheric correction; and correction the topographical effects (Jensen, 2004). The most often carried out procedures of preprocessing are geometric correction and atmospheric calibration. Which method would be applied, is dependent upon the goal of study.

The geometric correction is the first image processing step (pre-classification approach) carried out when the remotely sensed data are not geo-rectified (Lilleesand et al., 2004). However, georectification can be carried out as a post-classification approach to reduce the errors and distortions resulting from the geometric correction process. This step is influenced by the approach used to process a remotely sensed image, and therefore depends on the use for which the data is intended, and when the geo-rectification is done. Generally, it is more competent to begin with geo-rectifying the still unprocessed data. Therefore, all products that will result from the raw data will be automatically geo-rectified.

To obtain superior classification results, additional GCPs to the minimum number are commonly used. There is an error measurement technique that can compute the correctness of selected GCPs. It named the Root Mean Square (RMS) error, which is the distance between the input (source) position of a GCP in the input-matrix and the re-transformed position for the same GCP in the output-matrix. For the purposes of this study, all satellite data were projected Datum of WGS-84 Zone 48 S.

c. Selecting LULC Classification system

For the purpose of this study, LULC classification was modified from the LULC categories of the Indonesian National Standard no. 7645:2010 specified by the National Standard Agency of Indonesia which refers to the FAO's land cover classification system and ISO 19144-1 (BSN - National Standarization Agency of Indonesia, 2010), as described in Table 2.4.

Tabel 2.4. Land use and land cover classification and its general descriptions

LULC categories	General description
Forest	Areas covered by dense trees with relatively darker green color
Tea plantation	An intensively managed plantation. It is characterized by a homogenous canopy structure with single dominant species and regular spatial network and clear cut boundaries with neighboring vegetation.
Mixed plantation	Areas covered by a combination of several woody and fruity plantations such as Cassiavera (*Cinnamomum burmannii*), and local tropical fruits such as Orange (*Citrus sp*), Mangosteen (*Garcinia mangostana L*), Mango (*Mangifera indica*),. It is indicated by irregular patterns.
Shrub/bush	Areas covered by herbs, grass and non woody herbs. These areas usually correspond to recently opened areas, the first phase of land conversion into both mix plantation and tea plantation.
Agricultural land	Areas dominantly cultivated by paddy field and potatoes which characterized by inundating of fields from irrigation or rainfall.
Settlement	Areas occupied by houses or buildings including road network and other facilities.

Source:

The Indonesian National Standard No. 7645:2010 by the National Standardization Agency of Indonesia; 2010

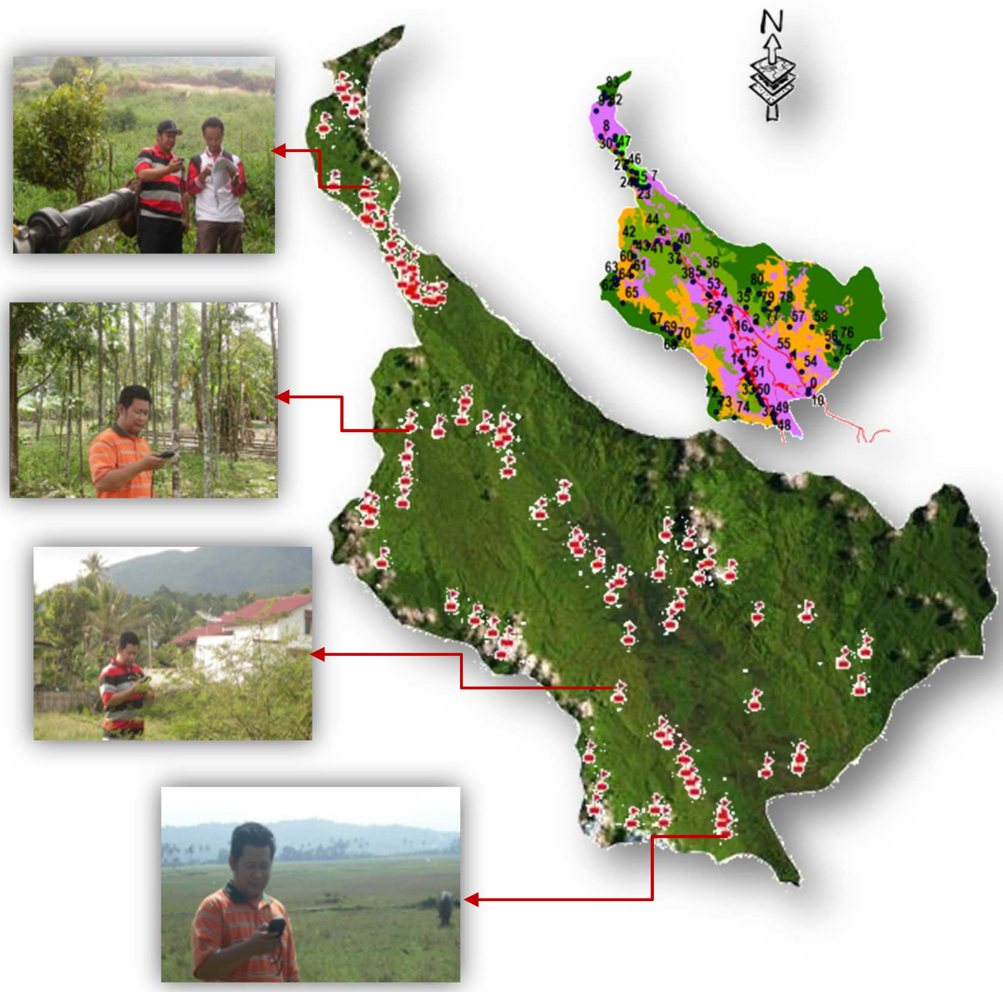


Figure 2.5 Ground truth activity in Batang Merao Watershed

in September 10-15, 2011

d. Ground Truth

Ground truthing is important for RS to properly identify objects, provide precise image registration and verify results. Therefore, field work and observations are essential if a supervised and/or knowledge based classification method will be used (Ismail et al., 2009; Yuksel et al., 2008). A total of 83 Ground Control Points (GCPs) were check during September 10-15, 2011 (Figure 2.5).

e. LULC classification

Supervised classification, the most popular method for assesing RS images (Ekpenyong, 2012; Ismail et al., 2009; Sun et al., 2008), was used to classify images. In support supervised classification, the MLC has been employed. It is offered in almost all RS and image processing software packages, and it is commonly applied as the typical supervised classification approach at present. As results, the interpretation of Landsat Image for LULC classification in this study can be shown in Figure 2.6

f. Accuracy assessment

Accuracy assessment is a post-classification step in LULC analysis and it is mainly the most common method for an estimation of classification approach execution. The acceptable accuracy values are relative, determined generally by the users themselves depending on the type of application. Accuracy values that are acceptable for specific application may be unacceptable for others.

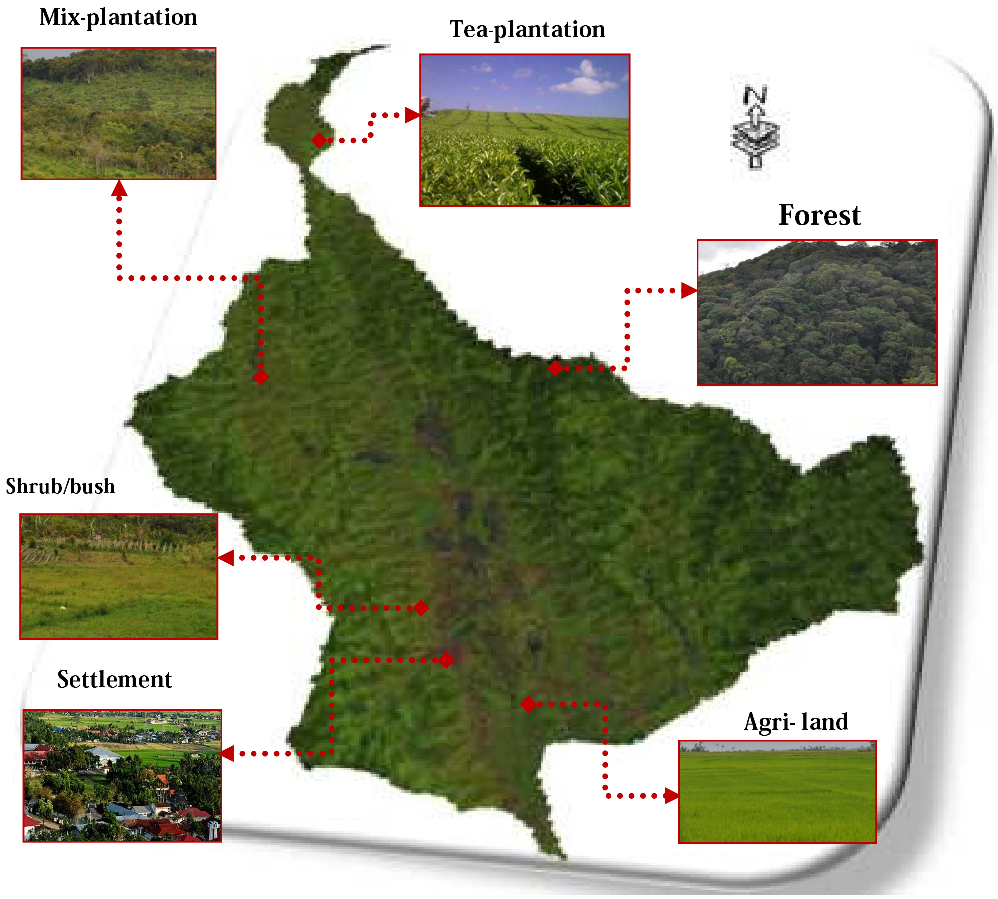


Figure 2.6. Interpretation of Landsat Image for LULC
(a sample of Batang Merao Watershed, Sumatera)

The method of accuracy assessment used in this study is based on the pixel scale to derive the accuracy of classification in the remotely sensed data, which resulted from the calculation of the error/confusion matrix. The the kappa coefficient is used in order to evaluate the overall accuracy of the classified images. It is generally known as a precision measure since it is considered as a measure of agreement in the absence of chance

(Lilleesand et al., 2004). The kappa statistic is calculated from the confusion matrix by using the following mathematical statement:

$$Khat = \frac{N\sum_{i=1}^{r} - \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})} \quad (2.1)$$

where r is the number of rows, x_i is the number of observations in row i and column i, x_{i+} and x_{+i} are the marginal totals of row and column, and N is the total number of observed pixels (Congalton, 1991). The value greater than 0.80 represents strong or good classification; the value between 0.40 and 0.80 means moderate classfication and the value less than 0.40 represents poor classification or agreement (Jensen, 2004).

2.3.3 Method for analysis of socioeconomic driving forces of LULC

A number of statistical tests were then performed with the LULC and socioeconomic data which were total population, number of farmers, Gross Domestic Regional Product (GDRP) agriculture, GDRP construction, total GDRP, average expenses, and HDI. A correlation matrix among the considered variables was firstly tested employing Pearson's correlation coefficient through bivariate analysis with statistically significance at $p < 0.05$. For further analysis of the relationship, the stepwise multiple regression analyses was carried out to measure the relationship among LULC.

The population pressure level was determined by using the Population Pressure Index (PPI) method (Soemarwoto, 1985; Ministry of Forestry, 2013). The index of population pressure is calculated as follows:

$$PPI = Z(1-\alpha)\frac{fPo(1+r)^t}{L} \quad (2.2)$$

where PPI is the population pressure index, Z is the minimum agriculture land-hold for proper life of each farmer (equal with rice 650 kg y^{-1}), α is the non-agricultural income, f is the proportion of farmer in population, P is the population, r is the population growth, t is time, and L is the total of agriculture area (ha). If the PPI index is less than one, it means there is no population pressure on land and that land can still accommodate agricultural activities (Soemarwoto, 1985; Ministry of Forestry, 2013).

2.3.4 Method for land degradation analysis

Land degradation was determined using the Universal Soil Loss Equation (USLE) method (Wischmeier and Smith, 1978). This is the most frequently used empirical soil erosion model worldwide (Shi et al., 2004) and remains the best known because of its sound scientific basis, low cost, direct application (Hood et al., 2002), a greater availability of input parameters (Sharma et al., 2011) and thse simplest model for erosion prediction, which estimates long-term average annual soil loss with acceptable accuracy (Beskow et al., 2009). It can be described in the following equation:

$$\mathbf{A} = \mathbf{R} \times \mathbf{K} \times \mathbf{L} \times \mathbf{S} \times \mathbf{C} \times \mathbf{P} \qquad (2.3)$$

where A is the annual soil loss (t ha^{-1} yr^{-1}), R is the rainfall/erosivity factor (mm y^{1}), K is the soil erodibility factor (t J^{-1} mm^{-l}), L and S are slope length and steepness factors, and C and P are the crop management and conservation factors.

2.3.5 Method for water quality analysis

Both Water Pollution Index (WPI) and STOrage and RETrieval (STORET) methods were used as they have been stated by Indonesian government through Environment Ministrial Decree No. 115/2003 (Ministry of Environment of Indonesia, 2003). The WPI was utilized for assessing the degree of water environmental pollution and the integrative assessment of river water quality standard in the watershed. STORET method was used in order to evaluate water quality status for decision maker. It is also widely used by government and non–government agencies (Sholichin et al., 2010). The basic concept of STORET is to compare between water quality data and its standard.

2.3.6 Method for assessment of watershed sustainability

The HELP indicators, a UNESCO integrated watershed sustainability index (WSI), was employed to assess the sustainability level of the watershed. The WSI was computed as all indicators have a certain range of value index (0 – 1). As the result, the watershed sustainability can be computed in the following equation:

$$\mathbf{WSI} = (\mathbf{H} + \mathbf{E} + \mathbf{L} + \mathbf{P})/\mathbf{4} \qquad (2.4)$$

in which WSI is the watershed sustainability index; H is the hydrologic indicator; E is the environmental indicator; L is the life indicator; and P is the policy indicator. All indicators have the same weight and value index (0 – 1). Finally, the WSI classification follows the UNDP's HDI classification (low for WSI<0.5, intermediate for WSI between 0.5 and 0.8, and high for WSI>0.8) (Chaves and Alipaz, 2006).

Finally, Figure 2.7 summarises the general methodological approach for this study. the following chapters describe the above method and show the results in details.

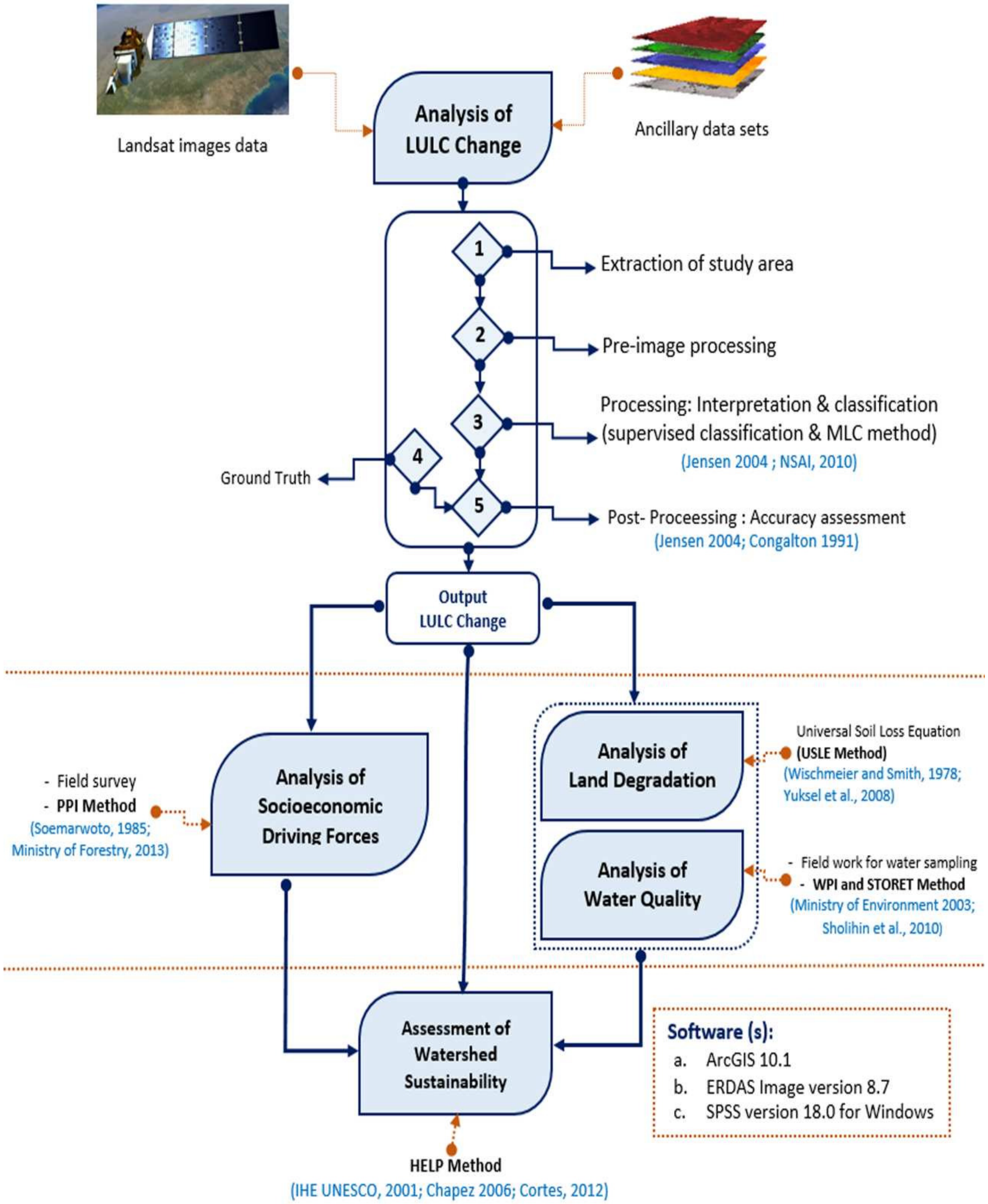


Figure 2.7. Summary of methodological approaches

Chapter 3

Dynamic pattern and driving forces of land use and land cover change in the humid tropical watershed

3.1 Introduction

Indonesia is a developing country in a humid tropical region where population has grown rapidly in the last decades, from 218.9 million (2005) to future 273.2 million (2025) (Ministry of Environment Indonesia, 2009), which placed Indonesia in the fourth most populous country in the world. Unfortunately, this megabiodiversity country is now under environmental pressure that Indonesia is also often seen as a country of environmental ruin whose biodiversity degradation is in alarming rates (Ministry of Environment Indonesia, 2009). Among tropical regions, Indonesia exemplifies this critical situation and experiences one of the highest rates of deforestation due to land change such as agricultural expansion, deforestation, and habitat fragmentation. The predominance of Indonesia in humid tropical forest clearing accounts for 12.8% of the total forest loss (Hansen et al., 2008). Other previous studies about LULC issues at national level in Indonesia reported that the causes of deforestation at national scale are becoming more complex, and cover various aspects of inappropriate policy implementation, socioeconomic, and political issues (Resosudarmo et al., 2012).

The awareness about the importance of LULC change study among global issues has risen for its nexus on global human security and quality of the environment. Furthermore, LULC change is a critical issue due to its great influence on land degradation (Symeonakis et al., 2007), biodiversity loss 2012), and eco-hydrological effects (Fu et al., 2005), and human life (Maitima et al., 2010). Analyzing LULC change and understanding the subsequent trends of change contribute to present complex dynamics of LULC and are important for planning and policy making (Reddy and Gebreselassie, 2011) and sustainable management of resources (Turner et al., Lambin, 2007).

Comprehension of land change requires a rigorous understanding of the underlying processes (Pena et al., 2007) and a full range of methods from the natural and social sciences (Ellis, 2010). One of the fundamental theories in land change study is the force that observes land change usually called "driving force" (Bürgi et al., 2004). It is generally accepted that there are two main driving forces of land change namely biophysical forces (Lambin et al., 2003) and socioeconomic or anthropogenic drivers (Su et al., 2011). Some studies disclosed that the relationship between land change and its causative factors is complex and dynamic (Minale, 2013), strongly related to socioeconomic factors (Long et al., 2007), and may occur at various temporal and spatial scales (Reid et al., 2000). As a consequence of complex interactions between biophysical and socioeconomic conditions (Reid et al., 2000), it constantly changes in response to the dynamic interaction between underlying drivers (indirect or root) and proximate causes (direct) (Lambin et al., 2003). In tropical regions, LULC change is associated with population growth (Ningal et al., 2008), population pressure (Dhas, 2008), agricultural expansion (Etter et al., 2006), and deforestation (Walker, 2004).

Located in the Midwest part of Sumatera Island, the Batang Merao watershed can be regarded as a typical case of the complex dynamics of humid tropical watersheds in Indonesia. The watershed is primarily based on agriculture, and hence an adequate and sustainable agricultural production depends on the appropriate land resource management. It is also considered as the most important buffer zone of Kerinci Seblat Park, a UNESCO's world heritage site in tropical rain forests. In addition, the watershed serves as the source of water resource, fresh water, and many important river systems in this region. In recent decades, however, the increasing of pressure on LULC gives significant impacts on the environment, particularly forest, soil, and water. Unfortunately, there is a lack of information about the dynamic change of LULC in this tropical watershed. Therefore, this paper aims at investigating dynamic patterns and socioeconomic driving forces of LULC change, and population pressure in the watershed. The final hope is that this research will give useful contribution in providing essential information for natural resources conservation, land use planning, and sustainable land management in humid tropical watersheds.

3.2 Material and Methods

3.2.1 Study area

Batang Merao watershed is located in the Kerinci Regency, a region in the western part of Jambi Province and in the middle of Sumatera Island, Indonesia. It lies between the latitude of 01°42'19"S and 02°08'14"S and longitude between

101°13’11”E and 101°32’20”E, as described in Figure 3.1. The watershed covers an area about 67,874.48 ha and consists of 10 sub regencies including 124 villages. The altitude ranges from 767 to 3,266 m above sea level. The watershed falls within the humid tropical zone characterized by dry and rainy seasons with an estimated annual mean precipitation of 2,495 mm y^{-1} over the last 20 years and annual mean temperature of 23.1^{0} C over the last 10 years. It plays an important role in serving regional economic development of Kerinci Regency and Jambi Province and is predominantly dependent on agriculture and tourism.

Since it is a buffer zone of a UNESCO tropical rainforest heritage site in Kerinci Seblat National Park, maintenance of the protected area around the watershed is also an essential requirement for the regional economic and environmental development. Agriculture is the principal occupation of the people of Batang Merao watershed who are mainly engaged in cultivation of Tea (*Camellia sinensis L*), Paddy (*Oryza sativa*), Potato (*Solanum tuberosum*), Cassiavera (*Cinnamomum burmannii*), and local tropical fruits such as Orange (*Citrus sp*), Mangosteen (*Garcinia mangostana L*), Mango (*Mangifera indica*), etc. Issues of environmental degradation such as deforestation, land degradation, and illegal logging are now among great concerns of the local government Jambi Province.

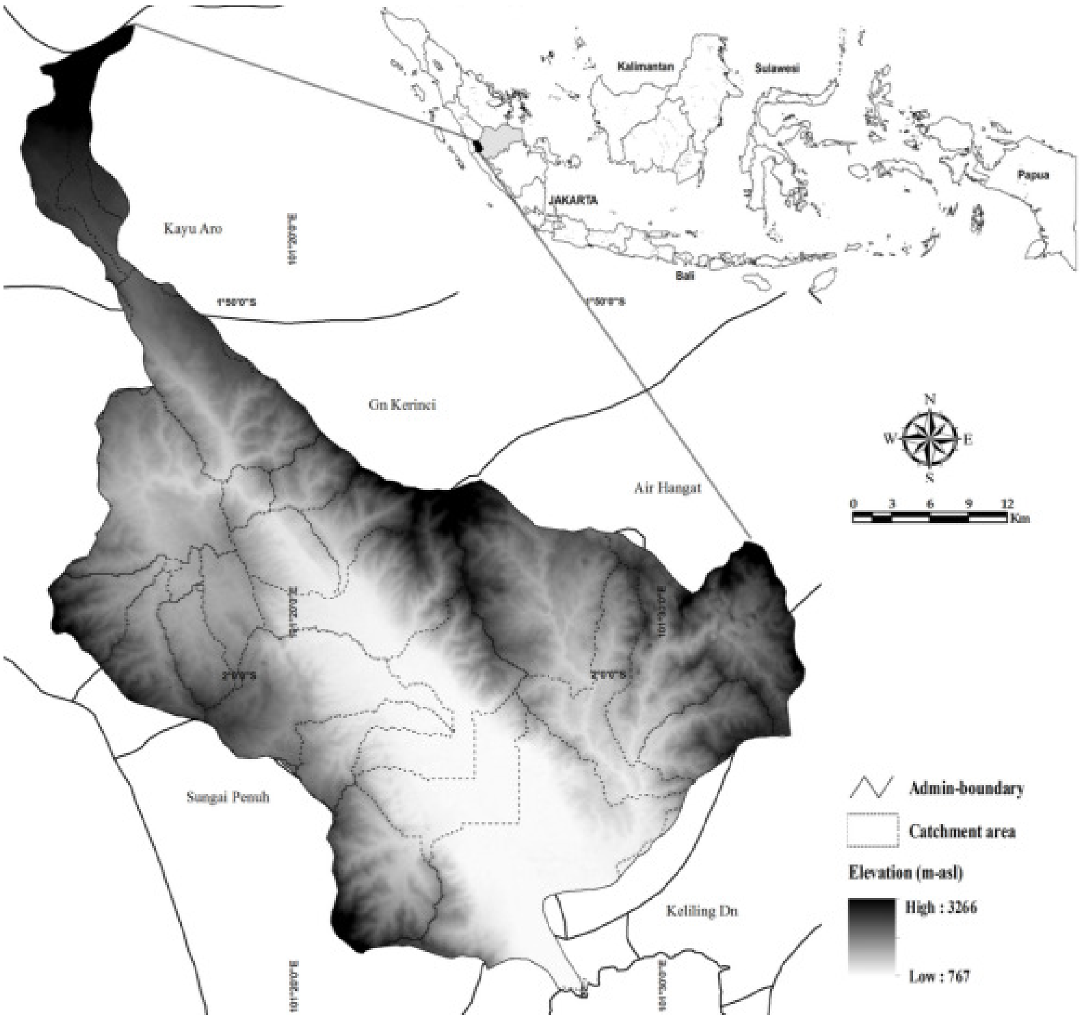


Figure 3.1 Study area in Batang Merao Watershed, Indonesia

Table 3.1 Data collection and its description

for analysis of pattern and driving forces of LULC change

Data	Description	Source
Landsat ETM	Path 126 / row 61 May 30, 2006 Nov 17, 2007 Feb 5, 2008 May 22, 2009 June 18, 2010 May 28, 2011	http://glovis.usgs.gov/
Administrative	Jambi Province Kerinci Regency Watershed Boundary	- Geospatial Information Agency of Indonesia (BIG) - Planning Agency of Jambi - Planning Agency of Kerinci - Forestry office of Batanghari (BPDAS)
LU planning map	Regional land use planning	
Demography	Population, statistics	Statistics of Kerinci Regency
Socioeconomic	Basic need, land-hold, income	Primary survey (248 respondents)
Ground truth	Ground truth 2011 for LULC classification	Field survey

3.2.2 Data collection

The details of data sets are described in Table 3.1. The data used for studying LULC change included historical Landsat satellite images covering Batang Merao watershed for the year of 2006-2011 (path 126/row 61) retrieved from the USGS Earth Resource Observation System (http://glovis.usgs.gov).

For supporting image analysis some ancillary data were used including ground truth data (83 samplings) acquired through the field survey (September 10-15, 2011), digital administrative map of Jambi Province provided by the Geo-spatial Information Agency of Indonesia, and digital watershed boundary map of Jambi Province published by the Ministry of Forestry of Indonesia. All the ancillary data were used to assist the training area in image classification and to collect the reference data in accuracy assessment.

Socioeconomic data were collected by primary survey of respondents in the study area. Semi-structured interviews with a total of 248 representative local people were conducted in order to analyze population pressure to the LULC. Furthermore, relevant secondary socioeconomic data such as demographic and gross domestic regional product (GDRP) data were collected from the statistical yearbooks provided by the statistical offices at all administrative levels.

3.2.3 Data analysis

In order to prepare the multitemporal satellite images for accurate change analysis, the Landsat images were pre-processed using standard procedures including Geo-referencing and geometric correction (Jensen, 2004) while the WGS datum 1984 was used as the coordinate system. Subsets of Landsat satellite images were rectified using orthophotos with UTM projection Zone 48 S using first order polynomial methods and nearest neighbor image re-sampling algorithm. A total of 83 Ground Control Points (GCPs) were functioned to note the Landsat image with the data rectification error of less than 1 pixel (0.165 of RMS Errors).

A total of six LULC categories were considered in this study namely forest, mix plantation, tea plantation, shrub/bush, agricultural land, and settlement. This classification was modified from LULC categories of Indonesian National Standar No. 7645:2010 by National Standard Agency of Indonesia referring to the FAO's land cover classification system and ISO 19144-1 (BSN - National Standarization Agency of Indonesia, 2010). Supervised classification, the most popular method for assesing remote sensing images (Perumal and Bhaskaran, 2010), was used to classify images. An accuracy assessment or confusion contingency matrix was implemented for evaluating the accuracy of the classified images. The error matrix functions to compare a relationship between the known reference data (ground truth) and the conforming outputs of image classification (Congalton, 1991). The kappa coefficient, the value for an estimation of how well remotely sensed classification accuracies to the reference data, was used for accuracy assessment (Jensen, 2004). The Kappa (***Khat)*** statistics (Congalton, 1991) was guided by the equation 2.1 (see chapter 2 pp 55). Furthermore, all LULC data were analyzed in ERDAS version 8.7 and Arc GIS version 10.1.

In order to investigate the socioeconomic driving forces which were significantly related to LULC change, a number of statistical tests were then performed with the LULC and socioeconomic data. A number of socioeconomic factors from the statistical yearbooks were selected for the analysis including total population, number of farmers, GDRP agriculture, GDRP construction, total GDRP, average expenses, and Human Development Index (HDI). These variables were initially computed for annual change rates, and subsequently the outputs were merged with derived LULC. A correlation matrix among the considered variables was firstly tested employing Pearson's correlation coefficient through bivariate analysis with statistically significance at $p < 0.05$. For further analysis of the relationship, the stepwise multiple regression analyses with forest, a major concern of LULC change, as dependent variable, was carried out to measure the relationship among LULC compositions in each part of the watershed. All of the statistical tests were performed in SPSS version 18.0 for Windows.

The conceptual framework of population pressure has frequently been used for describing relationship amongst land change, environmental degradation, and human activity. It assumes that population density will lead to greater competition for resources, and it will thus decrease land or even outright resource shortage. Among its growing theories, the population pressure level was determined by using the Population Pressure Index (PPI) method (Soemarwoto, 1985; Ministry of Forestry, 2013). The index of population pressure is calculated as described in equation 2.2 (see chapter 2 pp 56).

3.3 Results and Discussion

3.3.1 Distribution and dynamic pattern of LULC

The accuracy of LULC change along with the overall accuracy and the Khat coefficient are briefly explained in Table 3.2. The table shows that the user's accuracy of individual category was from 50% to 100%, and the producer's accuracy was from 68% to 100%. The overall accuracy of image classification was 81.93%, and the Kappa coefficient was 0.776. The Kappa coefficients indicated that the classified images showed moderate classification performance or moderate agreement.

Table 3.2 Accuracy assessment for supervised classification of LULC for 2011

LULC Classification	Reference Data							User's Accuracy
	F	**MP**	**TP**	**SB**	**AL**	**S**	**Total**	**(%)**
Forest (**F**)	**19**						19	100.00
Mix Plantation (**MP**)	1	**17**		1	1		20	85.00
Tea Plantation (**TP**)		1	**8**				9	88.89
Shrub/Bush (**SB**)		2		**7**	1		10	70.00
Agricultural Land (**AL**)		2		1	**12**		15	80.00
Settlement (**S**)		3		1	1	**5**	10	50.00
Total	20	25	8	10	15	5	**83**	**Overall Accuray** ***81.93%***
Producer's Accuray (%)	95.00	68.00	100.00	70.00	80.00	100.00		**Kappa coefficient** ***0.776***

The distribution of LULC and its changes for 2006 and 2011 is summarized in Table 3.3 and Figure 3.2. Through the study period, there were substantial changes in several LULC categories including settlement, agricultural land, and mix plantation: agricultural land increased from 13,454.08 ha in 2006 to 14,457.84 ha in 2011; settlement areas increased from 1,514.62 ha in 2006 to 1,634.8; and mix plantation, the biggest change in the study period, increased from 19,977.76 ha in 2006 to 24,034.57 ha in 2011. Contrarily, forest decreased from 16,425.48 ha in 2006 to 12,304.79 ha in 2011. Furthermore, the dynamic patterns of LULC change are also represented in Figure 3.3. It appears that forested land has changed into another LULC type. Its change to mix plantation and agriculture could be the indication of a trend and need of agricultural market and regional economic development.

Table 3.3. Summary of LULC change and annual rate of change

LULC Classification	2006		2011		Change 2006-2011	Annual rate of change
	ha	%	ha	%	ha	%
Forest	16,425.48	24.20	12,304.79	18.13	-4,120.69	-5.02
Mixed plantation	19,977.76	29.43	24,034.57	35.41	4,056.81	4.06
Tea plantation	1,070.08	1.58	989.68	1.46	-80.39	-1.50
Shrub/bush	15,432.46	22.74	14,452.70	21.29	-979.76	-1.27
Agricultural land	13,454.08	19.82	14,457.84	21.30	1,003.76	1.49
Settlement	1,514.62	2.23	1,634.89	2.41	120.27	1.59
	67,874.48		**67,874.48**			

In general, the patterns showed a tendency towards more land being brought under mix plantation and agricultural land. These given data expressly stated that the increase in cultivated function resulted in deforestation, meaning that some forest areas (protected areas) were removed and converted to cultivated areas, such as mix plantation, paddy-field, and potato plantation.

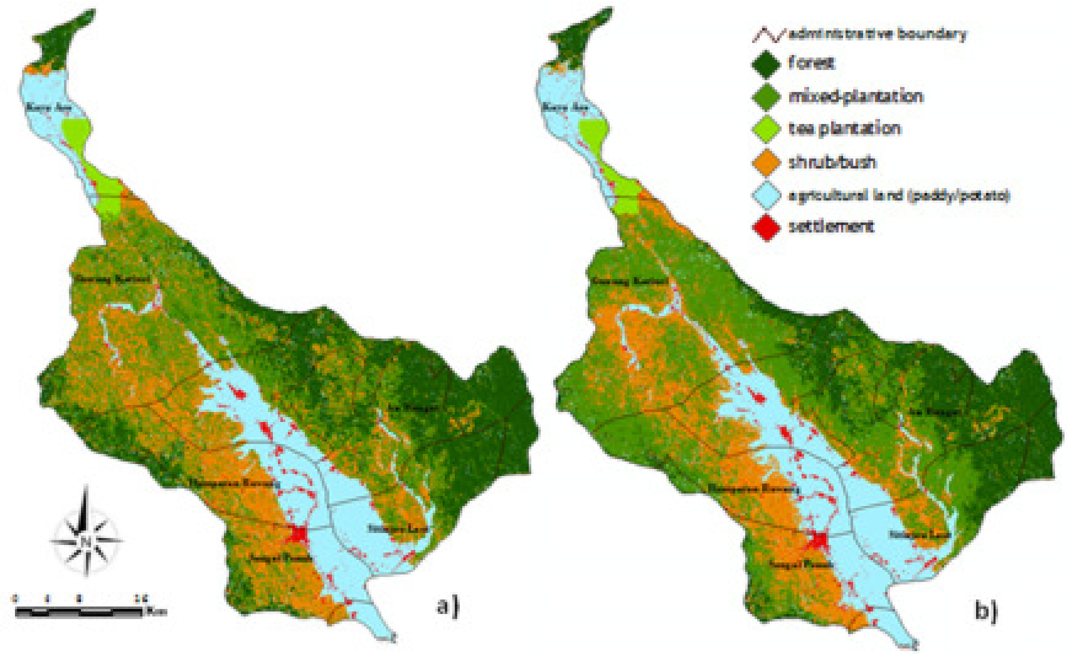


Figure 3.2. Land use land cover maps of the Batang Merao Watershed a) 2006, and b) 2011

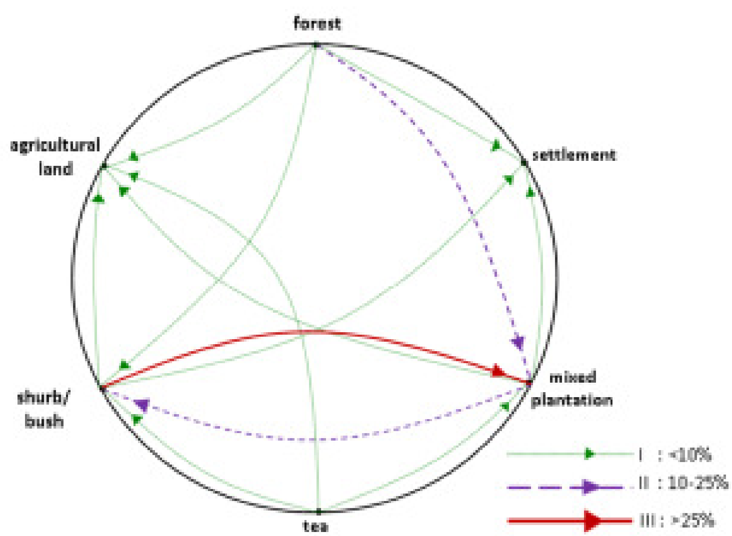


Figure 3.3. The dynamic patterns of LULC in the period of 2006-2011

Table 3.4. Annual socioeconomic determinants

Determinants	2006	2011	Change rate
Total population (person)	183,033	229,089	5.03
Number of farmers (person)	76,546	100,424	6.24
GDRP agriculture (Rupiah)	625,435	826,590	6.43
GDRP Construction (Rupiah)	45,181	64,572	8.58
GDRP Total (Rupiah)	1,253,561	1,655,197	6.41
Total Expenses (Rupiah)	619,000	635,000	0.50
HDI	72.20	74.26	0.57

Note:

1 USD = ± 11,000 Rupiah (Indonesian Currency; August 2013)

3.3.2 Socioeconomic driving forces of LULC

Annual socioeconomic change rates were summarized in Table 3.4. The result of Pearson's correlation matrix analysis indicated that the forest land was significantly correlated with five of seven socioeconomic factors namely total population, number of farmers, GDRP agriculture, total GDRP, and HDI. Meanwhile, GDRP Construction and total expenses were not related with forest land conversion.

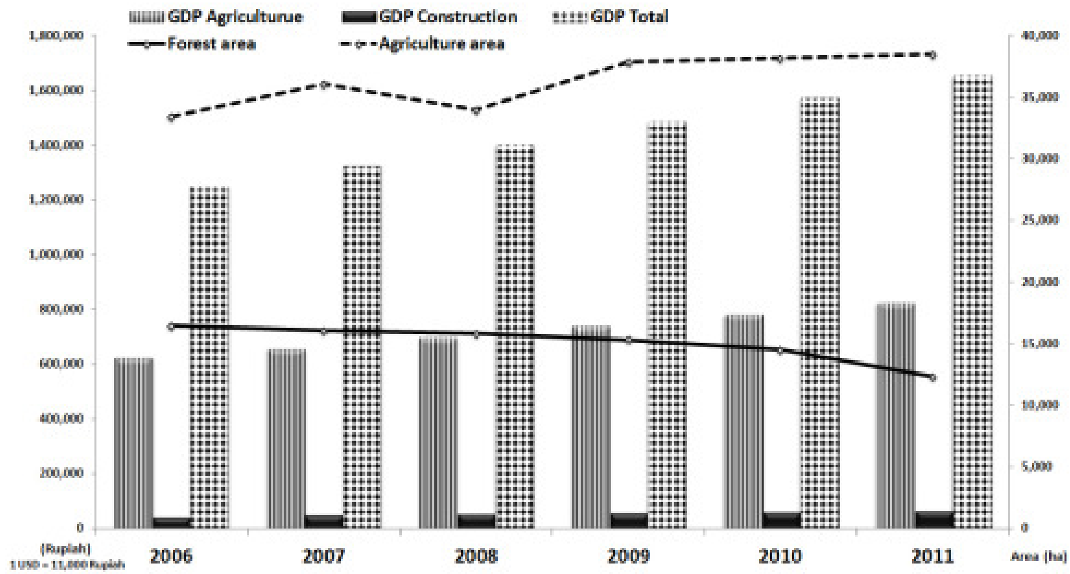


Figure 3.4. Changes and trends in the regional economic sharing and LULC areas

Table 3.5. Regression analysis of LULC driving forces

Parameter	Coefficient	t-statistic	Sig.
Intercept	-2.79	-428.44	<.05
Total population	-0.37	-166.27	<.05
Number of farmers	-0.22	-148.98	.05
GDRP Agriculture	-0.61	-199.99	<.05
GDRP Total	1.05	224.23	<.05
HDI	0.12	205.05	.05
			R^2 = .938
			adjusted R^2 = .917

As summarized in Table 3.5, the output of multiple regression analyses confirmed that the forest land changes were contributed by five proximate driving forces. The GDRP, which is considered as an indicator used for measuring the size of the regional economy, indicated its coefficient at a high record of +1.05 supported by GDRP agriculture score of -0.61. The rapid regional economic growth was parallel with forest degradation and agricultural expansion, as represented in Figure 3.4. Therefore, due to the high deforestation rate in the watershed, it is necessary to give more attention about the ecological impacts of LULC change in order to achieve sustainability for both society and environment.

3.3.3 Population pressure in Batang Merao watershed

In order to better understand the population pressure on land, the population pressure index year 2006 and 2011 were examined and summarized in Table 3.6. The data indicated that Batang Merao watershed was in high population pressure. The lowest PPI was Sungai Penuh city with the value of 0.46 (2006) and 0.89 (2011), and the highest PPI was Kayu Aro sub-regency at the value of 1.26 (2006) and 1.89 (2011), respectively. Accordingly, the average PPI level increased from 0.72 in 2006 to 1.30 in 2011. This result means that agricultural carrying capacity of the watershed could support the population of 189,444 in 2006; on the contrary, it could not accommodate the population of 229,089 in 2011; thus, there was an ecological overshoot in the watershed in 2011.

Table 3.6. Population pressure level of Batang Merao watershed

Year	Category		Population Pressure Index		
	No Pressure	Under pressure	The lowest index	The highest index	Average
2006	4 sub-regencies	3 sub-regencies	0.46 Sungai Penuh	1.26 Kayu Aro	0.72
2011	2 sub-regencies	5 sub-regencies	0.89 Sungai Penuh	1.89 Kayu Aro	1.30

This result was not too different with the previous study on the PPI level at provincial level and regional level in which the average PPI level in Jambi Province was 0.95 (2006) and 1.02 (2010) (Rusli et al., 2010) respectively. Furthermore, the findings of this research agreed that the consequent high pressure on resources are feared to have adverse effects on the existing natural resources of the area as the demand for food and other necessities would increase. Among the major causes, demographic factors, especially an increase in local population including household structure and land-hold, play a significant role in LULC change (Lambin and Geist, 2007).

3.4 Conclusion

The structural pattern of LULC in Batang Merao watershed, according to the distribution pattern, was forest (35.41%), agricultural land (21.30%), shrub/bush (21.29%), forest (18.13%), settlement (2.41%), and tea plantation (1.46%), respectively. Meanwhile, the dynamic pattern of LULC of forest was mix plantation, shrub/bush, agricultural land, and settlement.

The driving forces of LULC from the proximate factors included GDRP total, GDRP agriculture, total population, number of farmers, and HDI. The results suggested that changes in LULC and its dynamics were closely associated with human activities in the region such as the expansion of agricultural area (mix plantation and paddy field).

The growing population pressure and its associated problems, such as the increasing demand for land and agricultural products, limited land-hold shares, and the lack of non-agricultural income, had been the major driving forces of LULC. Hence, attention should be given to the introduction of proper land resource uses and management practices and secure land tenure systems.

Currently, Batang Merao watershed, which might be the representative of many other watersheds in the humid tropical areas, reflected a critical dynamic change of LULC due to driving forces and population pressure. In regard to sustainable land management, conservation strategies for natural, agricultural, and pro-environment local economic activities, should be a priority for land managers and relevant stakeholders.

Chapter 4

Ecological impacts of land use and land cover change

4.1 Section 1: Ecological impact of land use land cover change on land degradation

4.1.1 Introduction

Studying LULC change is a critical requirement for the assessment of potential environmental impacts and the development of effective land management and planning strategies (Leh et al., 2011). Knowledge of the nature of LULC change and its configuration across spatial and temporal scales is consequently indispensable for sustainable environmental management and development (Turner et al., 1995). LULC is always dynamic when it constantly changes in response to the dynamic interaction between underlying drivers and proximate causes (Lambin et al., 2003).

Change in LULC is a key driver of environmental changes (Lambin et al., 2001) on all spatial and temporal scales (Turner et al., 1994) and it can be a major threat to biodiversity (Verburg et al., 1999). Monitoring LULC change in landscape of watershed is becoming an important issue across various fields of development and sustainable management. Landscape changes include not only damage by agriculture but also degradation of historic value and land conservation functions (Ohta and Nakagoshi, 2011).

During the last few decades, LULC change and its impacts have become major problems and serious threats to environmental conditions. Many watersheds today suffer from several detrimental problems such as severe soil erosion, flood, drought, and declining land productivity or land degradation. Land degradation, a synonym for soil degradation (Kertész, 2009) that implies soil functions have been damaged by climate or human activities (Maitima et al., 2004), is a critical environmental problem in many countries (Ouyang et al., 2010) especially in developing countries (Ananda and Herath, 2003). About 85% of land degradation in the world is associated with soil erosion (Oldeman et al., 1991) such as in the Citarik, West Java about 94-103 ton ha^{-1} y^{-1} (Kusumandari and Mithcell, 1997). Furthermore, land degradation has major implications for society in economic, social, and environmental perspectives.

Information on LULC dynamics and its impacts is very important for landscape management because it creates key environmental information for many resource management and policy purposes. Therefore, it is very useful for planners and policy makers to initiate remedial analysis on LULC change and land degradation. Furthermore, to strengthen the conservation and protection of the ecological environment, comprehensive planning is necessary with considerations that include balancing the social, safety, ecology, and landscape and treating the whole watershed as a management unit (Wu and Feng, 2006).

Batang Merao Watershed was selected for this research because it is the most important watershed around Kerinci Seblat National Park (KNSP), the biggest natural protected area in Sumatera. Batang Merao Watershed has a prominent role as buffer zone for Kerinci Seblat National Park. Land degradation in Batang Merao watershed will affect the sustainability of conservation function of KNSP and downstream areas such as Sungai Penuh City and Merangin Regency. The purpose of this study was to analyze LULC changes, land degradation and the relationship between them in three different years (1990, 2000 and 2010).

4.1.2 Material and methods

4.1.2.1 Study area

Batang Merao Watershed is located in the northwest of Jambi Province which its geo-location is at 01°42’19” - 02°08’14” South, 101°13’11” - 101°32’20” East (Figure 4.1). The elevation ranges from 766 to 3,236 m above sea level. The total area of the study site is 67,874.48 ha. This area covers ten sub regencies and 124 villages. It is situated in a tropical zone where the annual mean precipitation is 2,495 mm y^{-1} based on the last 20 years and the annual mean temperature is 23.1^{0} C based on the last 10 years.

4.1.2.2 Data

The basic data required to meet the objectives of this study were Landsat image data, Aster Global Digital Elevation Model (Aster GDEM), digital land use maps, climate data (annual rainfall) and Universal Soil Loss Equation (USLE) data.

Table 4.1 Data collection and its description

for analysis of the relationship between LULC change and land degradation

Data	Description	Source
Landsat TM	Path 126 / row 61 July 13, 1990 May 5, 2000 June 18, 2010	http://glovis.usgs.gov/
DEM	Aster GDEM 30 m	http://demex.cr.usgs.gov/
Administrative	Jambi Province Kerinci Regency Watershed Boundary	- Geospatial Information Agency of Indonesia (BIG) - Planning Agency of Jambi - Planning Agency of Kerinci - Forestry office of Batanghari (BPDAS)
Soil series map	Soil type 1990, 2000, 2010	
Rainfall data	Monthly rainfall and distribution 1990-2010	
Land use planning map	Regional land use planning	
Ground truth	Ground truth 2011	Field survey

For supporting image analysis, some ancillary data were used including ground truth data acquired through a field survey in August – September 2011, a digital administrative map of Jambi Province provided by the Gespatial Information Agency of Indonesia and a digital watershed boundary map of Jambi Province published by the Ministry of Forestry of Indonesia. All the supplementary data were used to assist in image classification and to collect reference data for accuracy assessment, as described in Table 4.1.

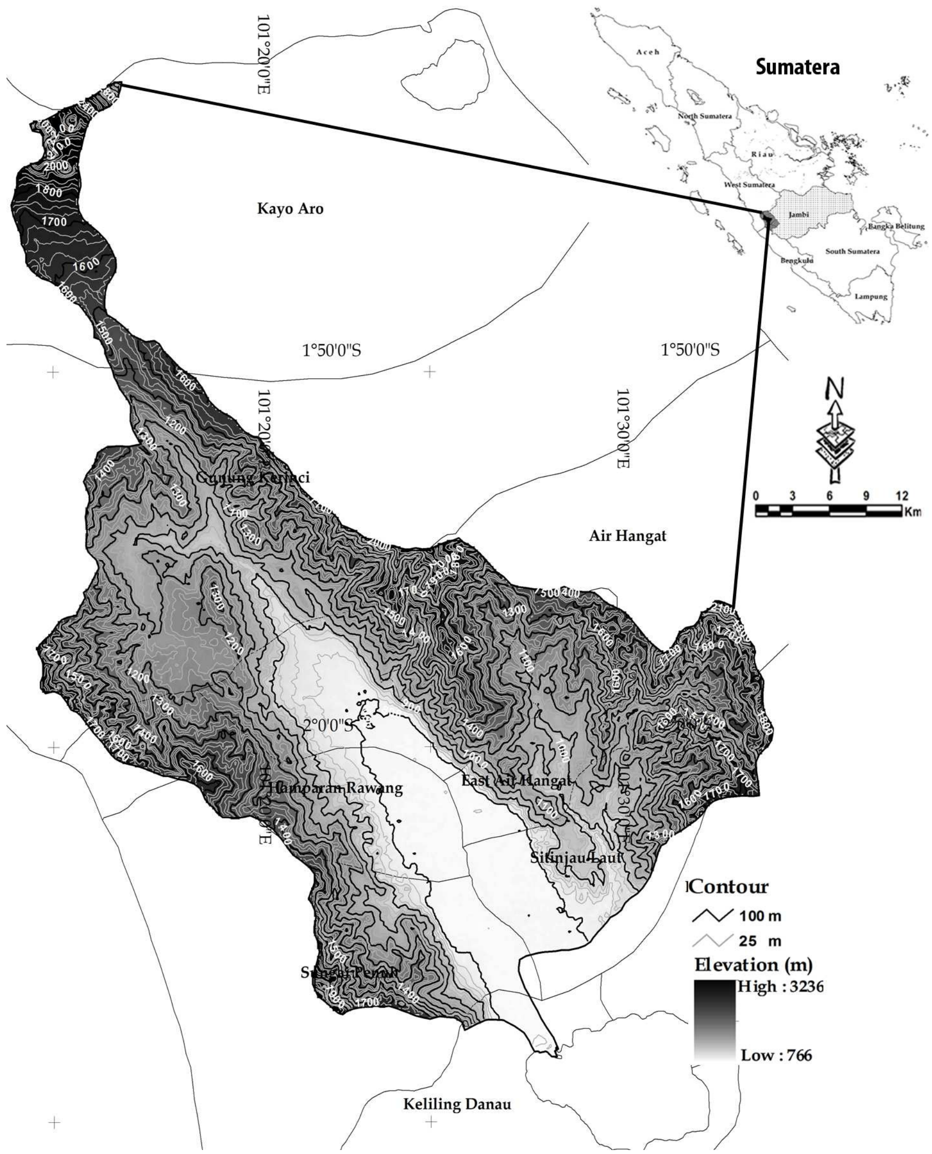


Figure. 4.1. Batang Merao Watershed showing the elevation

at 25m and 100 m contour intervals

4.1.2.3 Analysis

Supervised classification, the most widely used technique for quantitative analysis of remote-sensing image data (Prakasam, 2010; Pôças et al., 2011), was used to perform image classification. To evaluate the accuracy of the classified images, an accuracy assessment or confusion contingency matrix was implemented. The error matrix compared the linkages between known reference data (ground truth) and the corresponding results of an automated classification (Congalton, 1991). The Kappa coefficient, the value for estimating how accurate the remotely sensed classification is in the reference data (Jensen, 2004), was used for accuracy assessment. The Kappa (***Khat)*** formula is described in equation 2.1 (chapter 2 pp 55).

LULC classification was modified from the LULC categories of the Indonesian National Standard no. 7645:2010 specified by the National Standard Agency of Indonesia which refers to the FAO's land cover classification system and ISO 19144-1 (BSN - National Standarization Agency of Indonesia, 2010). Because of differences in scale, accuracy and type of LULC categories, synchronization and generalization were performed, resulting in six categories: forest, mix plantation, tea plantation, shrub/bush, agricultural land and settlement, as described in Table 2.4 (see chapter 2 pp 51).

The potential soil erosion was determined using the USLE method (Wischmeier and Smith, 1978; Palma et al., 2007). This is the most widely used method and the simplest model for predicting soil erosion (Beskow et al., 2009) and still remains the best known because of its scientific basis, ease of use, low-cost and direct applicability in watershed (Sharma et al., 2011) and forest system (Hood et al., 2002). It can be described in equation 2.3 (see chapter 2 pp 57).

Statistical analysis with Pearson Correlation Coefficient was applied to identify the relationship between land use land cover change and land degradation. In this analysis the land use category served as the independent variable and the rate of land degradation served as the dependent variable. Due to the different scale between land use type (nominal scale) and land degradation class (ordinal scale), the land degradation class needed to be aggregated using statistics method "summarated rating scale". The next step was bivariate statistics correlation analysis between land use degradation to identify the relationship between land use land cover change and land degradation. All image processing, classification and change detection were performed using ERDAS Imagine 8.7 while the GIS analysis was carried out using ArcGIS 10.1. Furthermore, statistical analyses were conducted using PSAW SPSS Statistics 18.

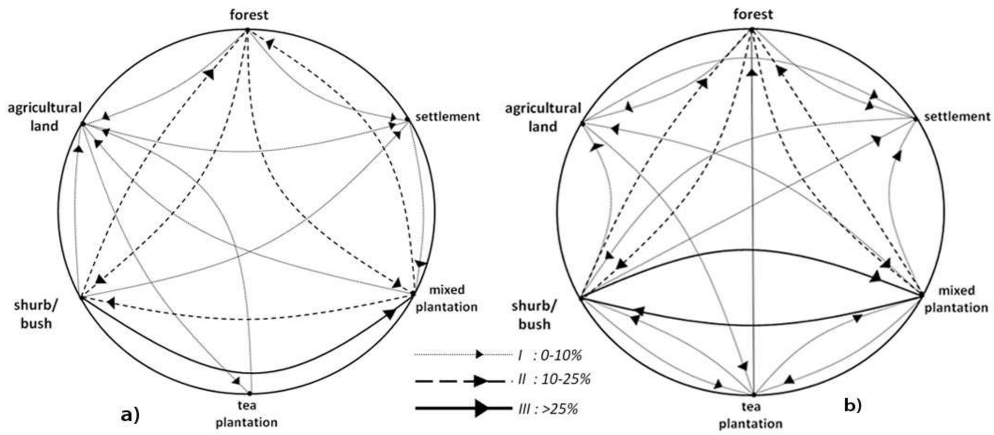


Figure 4.2. The dynamic patterns of land use land cover change in Batang Merao Watershed in the period of: a) 1990–2000 and b) 2000-2010

4.1.3 Results and Discussion

4.1.3.1 Changes of LULC and land degradation

The distribution of LULC and its changes for 1990, 2000 and 2010 is summarized in Table 4.2. The dynamic patterns of LULC change are also represented in Figure 4.2 and the spatial distribution of LULC over time is clearly visible in Figure 4.3. Through the period of study, several LULC categories had increased such as settlement, agricultural land and mix plantation. For example, settlement areas have increased from 1,150.29 ha in 1990 to 1,530.51 ha in 2000 and 1,587.48 ha in 2010. Mix plantation areas have also shown an increase of 36.60% (period 1990-2000) and 3.44% (period 2000-2010). On the other hand, forest decreased from 20,297.58 ha in 1990 to 16,989.12 ha in 2000, and 15,536.66 ha in 2010.

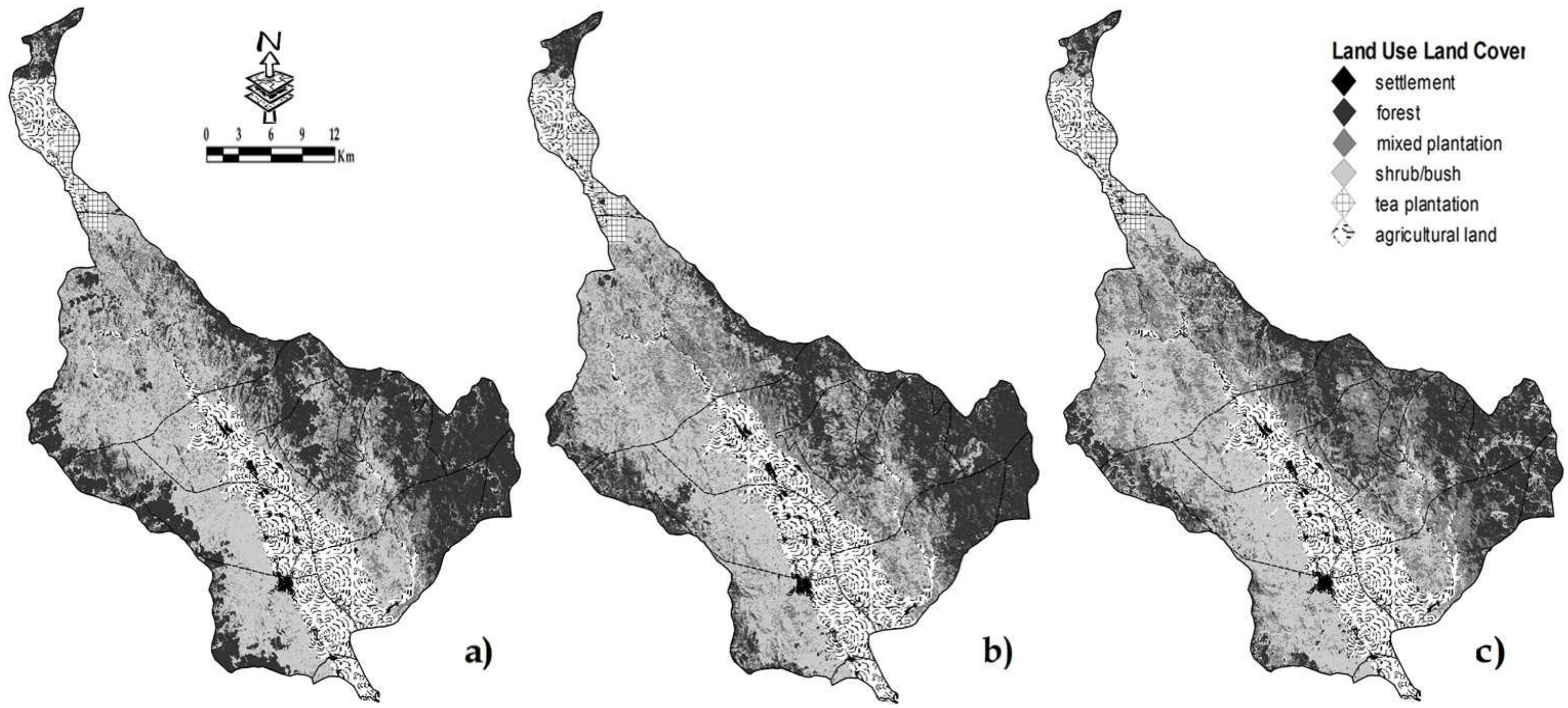


Figure 4.3 Land use land cover maps of the Batang Merao Watershed in; a) 1990; b) 2000; and c) 2010

Table 4.2. LULC change in 1990, 2000, and 2010

LULC Classification	1990		2000		2010		Change				Average rate of change			
							1990 - 2000		2000 - 2010		1990 - 2000		2000 - 2010	
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
forest	20,297.58	29.90	16,989.12	25.03	15,536.66	22.89	-3,308.46	-16.30	-1,452.46	-8.55	-330.85	-1.63	-145.25	-0.85
mix plantation	11,177.02	16.47	15,267.43	22.49	15,792.12	23.27	4,090.41	36.60	524.69	3.44	409.04	3.66	52.47	0.34
tea plantation	931.46	1.37	1,078.82	1.59	997.71	1.47	147.35	15.82	-81.10	-7.52	14.74	1.58	-8.11	-0.75
shrub/bush	21,587.39	31.80	19,734.09	29.07	20,154.28	29.69	-1,853.29	-8.59	420.18	2.13	-185.33	-0.86	42.02	0.21
agricultural land	12,730.75	18.76	13,274.52	19.56	13,806.23	20.34	543.77	4.27	531.71	4.01	54.38	0.43	53.17	0.40
settlement	1,150.29	1.69	1,530.51	2.25	1,587.48	2.34	380.22	33.05	56.98	3.72	38.02	3.31	5.70	0.37
Total	67,874.48	100.00	67,874.48	100.00	67,874.48	100.00								

The accuracy of LULC change along with the overall accuracy and the Khat coefficient is summarized in Table 3.2 (chapter 3 pp 69), previously. The table shows that the user's accuracy of individual category ranged from 50% to 100% and the producer's accuracy ranged from 68% to 100%. The overall accuracy of image classification was 81.93% and the Kappa coefficient was 0.776. The Kappa coefficients indicated that the classified images showed moderate classification performance or moderate agreement.

Table 4.3 and Figure 4.4 show a clear pattern of changes characterized by potential land degradation levels. There was an increase in the total area with very high levels of land degradation namely 19.55% in the period of 1990-2000 and 10.17% in the period of 2000-2010. At the same time, the area with very low level of land degradation decreased by -5.70% and -16.54% in 1990-2000 and 2000-2010, respectively. Batang Merao Watershed also exhibited potential land degradation as the mean annual land degradation increased from 128.03 ton ha^{-1} y^{-1} in 1990 to 144.68 ton ha^{-1} y^{-1} in 2000, and 194.14 ton ha^{-1} y^{-1} in 2010.

Table 4.3. Distribution of potential land degradation in Batang MeraoWatershed, Sumatera

Land Degradation Level	Potential Soil Loss	1990		2000		2010		Change				Average rate of change			
								1990 - 2000		2000 - 2010		1990 - 2000		2000 - 2010	
	ton ha^{-1} y^{-1}	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%	(ha)	%
Very low	< 5	32,156.14	47.38	30,322.57	44.67	25,306.09	37.28	-1,833.57	-5.70	-5,016.48	-16.54	-183.36	-0.57	-501.65	-1.65
Low	5 – 10	4,584.36	6.75	1,616.81	2.38	3,837.67	5.65	-2,967.55	-64.73	2,220.86	137.36	-296.76	-6.47	222.09	13.74
Moderate	10 – 30	1,743.60	2.57	1,220.02	1.80	1,681.19	2.48	-523.58	-30.03	461.17	37.80	-52.36	-3.00	46.12	3.78
High	30 – 60	2,800.14	4.13	2,926.87	4.31	2,028.86	2.99	126.74	4.53	-898.01	-30.68	12.67	0.45	-89.80	-3.07
Very high	> 60	26,590.24	39.18	31,788.20	46.83	35,020.68	51.60	5,197.96	19.55	3,232.47	10.17	519.80	1.95	323.25	1.02
Total		67,874.48	100.00	67,874.48	100.00	67,874.48	100.00								

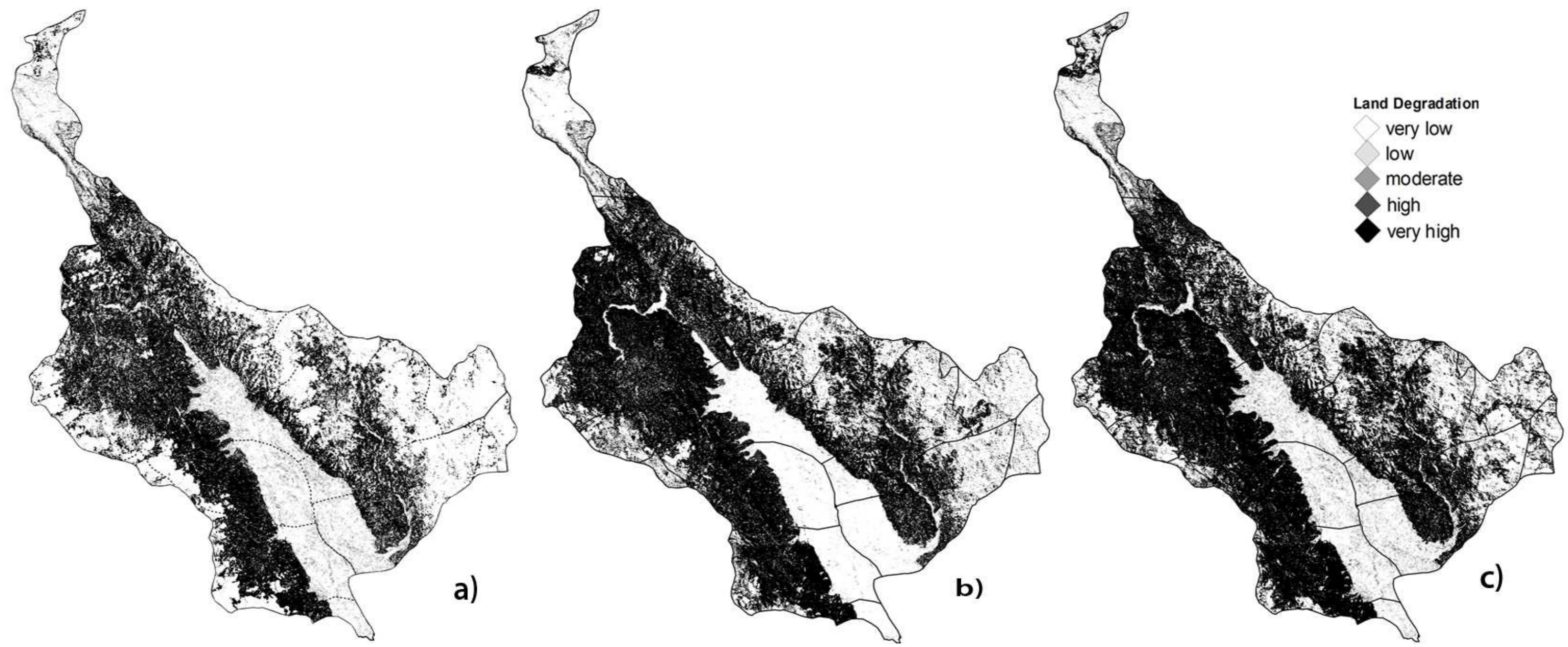


Figure 4.4. Land degradation maps of the Batang Merao Watershed at: a) 1990; b) 2000; and c) 2010

Table 4.4 Pearson's correlation between LULC type and land degradation

LULC Type	Statistical Indicator	Land degradation
Forest	Pearson Correlation	**-0.86**
	Sigh. (2-tailed)	0.34
Mix plantation	Pearson Correlation	**-0.74**
	Sigh. (2-tailed)	0.47
Tea plantation	Pearson Correlation	0.15
	Sigh. (2-tailed)	0.91
Shrub/bush	Pearson Correlation	**-0.49**
	Sig. (2-tailed)	0.67
Agricultural land	Pearson Correlation	0.95
	Sig. (2-tailed)	0.21
Settlement	Pearson Correlation	0.75
	Sig. (2-tailed)	0.46

4.1.3.2 Relationship between LULC change and land degradation

The result of Pearson correlation analysis was summarized in Table 4.4. The result depicted a negative correlation between several types of land use land cover and the rate of land degradation: forest (-0.86), mix plantation (-0.74) and shrub/bush (-0.49), respectively. General understanding of this results is that the negative correlation implied that the larger the forest area, mix plantation, and shrub/bush are, the lower the land degradation is. However, there were some positive correlations between low-vegetation land use type and non-vegetation type toward the rate of land degradation: agricultural land (0.95), settlement (0.75) and tea plantation (0.15), respectively.

4.1.4 Conclusion

In general, the results of the study disclosed that the Batang Merao Watershed had been under continual LULC changes from 1990 to 2010. Deforestation due to agricultural activities and increasing demand for settlement had imposed a threat of land degradation. This information is essential to preserve the natural protected areas. The results also showed that the areas were dominated by high levels of land degradation. The mean annual potential land degradation amounted to 128.03 ton ha^{-1} y^{-1} in 1990, 144.68 ton ha^{-1} y^{-1} in 2000 and 194.14 ton ha^{-1} y^{-1} in 2010. This research showed that there was a relationship between type of land use land cover and land degradation. Vegetation played an important role in protecting soil from erosion loss and is the key factor affecting land degradation in the watershed (Zhou et al., 2008). Vegetation cover affected the land degradation because of its litter production, organic matter accumulation, and plant roots (Wijitkosum, 2012).

The results also suggested that changes in LULC and its dynamics were closely associated with human activities in the region such as the expansion of paddy fields and settlements. It showed areas with a high potential of land degradation areas as indicated by the mean annual land degradation in the period of study. Among the USLE factors, the value of the LULC factor was dynamic over time and increased the total value and level of potential land degradation. The wide range of land degradation was subject to agricultural activities.

Assessment of LULC dynamics and its linkages is an essential part in sustainable land management that can help people optimize land use and minimize environmental impacts such as land degradation. Therefore, in order to prevent the areas from an extremely high level of land degradation, the wise use of land cover and soil conservation program are highly recommended to be widely implemented in the tea plantation and agricultural land.

4.2 Section 2: Ecological impact of land use and land cover change on water quality

4.2.1 Introduction

The linkage between land change and water resources are complex (Weatherhead and Howden, 2009). Land use land cover (LULC), one of the major environmental changes occurring around the globe (Zhang and Wang, 2012), has direct impacts on hydrologic systems within a watershed. The impacts of land change on the hydrology have been a major landscape and hydrol-ecologycal research topic over the last decade (Zhou et al., 2012). Water quality is one of such factors affected by land change and which is sensitive to changes in landscape patterns in a watershed (Xia et al., 2012), and it is generally linked to LULC in catchments (Ahearn et al., 2005). Water quality parameters in various aquatic systems have been closely linked to the proportions or types of land use within a watershed (Lee et al., 2009) and have been influenced by different landscape types (Fu et al., 2005).

Since the complex and dynamic relationships between land and water quality are yet to be elucidated and may differ substantially in developing countries due to differences in land use and land management practices (Baker, 2003), this study is very important to determine the status of river water quality and it is therefore important for developing integrated watershed management. Investigating the relationship between them has been recognized as a critical point for predicting potential pollution and developing watershed management practices (Xiao and Ji, 2007). In addition, this study can address the issue of land and water sustainability with appropriate land use practices and water protection management. However, more research especially in tropical region is needed because findings of this concern so far vary amongst the existing watersheds.

Due to dynamic land change especially deforestation, most of watersheds in Indonesia are still in critical level in both soil and water condition. Unfortunately, the studies of water quality were mostly done in the regions of Java Island, such as in Jakarta (Suwanda et al., 2011), West Java (Fulazzaky, 2010), and East Java (Sholichin et al., 2010). There is a general lack of information about water quality in watershed outside Java Island. To overcome the problems, Indonesian Government through the Ministry of Environment issued regulation on water quality management and pollution control in 2003 (Ministry of Environment of Indonesia, 2003). River water quality in Batang Merao watershed was classified in Category B (for service purpose while category A is for drinking water). Unfortunately, both river status and land use condition have not been evaluated neither their quality nor their linkage.

Batang Merao watershed is an important upland watershed in Sumatera (Indonesia), belonging to the Kerinci Seblat National Park, the UNESCO's tropical rainforest heritage site. It is a very important watershed for the people and the environment of Sungai Penuh City and Kerinci Regency as it supports various economic activities, such as fishing, irrigation, agriculture, micro-hydro electric power, domestic water supply, and tourism. These activities have potentially created negative effects on the water quality over time. Unfortunately, there is a general lack of information about the water quality and land use land cover on the hydrology of the catchment in this tropical landscape. Hence, the objective of this paper is to investigate the dynamic of land use, water quality status and their relationship the watershed. By studying the relationship between land use change and water quality, issues on sustainability can be addressed and integrated with better land use practices and water protection strategies.

4.2.2 Material and methods

4.2.2.1 Study area

Batang Merao watershed is located in the northwest of Jambi Province and in the middle of Sumatera Island, Indonesia. It is bounded by latitude between 01°42’19” - 02°08’14” South and 101°13’11”- 101°32’20” East (Figure 4.5). The altitude ranges from 767 to 3,266 m above sea level. The watershed falls within the humid tropical zone characterized by dry and rainy season with an estimated annual mean precipitation of 2,495 $mm.y^{-1}$over the last 20 years (Figure 4.6) and annual mean temperature of $23.1^{0}C$ over the last 10 years. The watershed, which covers 10 sub regencies and 124 villages, plays an important role in serving regional economic development of Kerinci Regency and Jambi Province. It supports various human activities along its stretch, such as agricultural activity, fishing, tourism, etc. Since it is a buffer zone of a UNESCO tropical rainforest heritage site in Kerinci Seblat National Park, maintenance of the protected area around the watershed is also an essential requirement for regional development. The watershed is facing environmental degradation that is critically threatened by the effects of anthropogenic activities. This issue is among great concerns of the local government of Kerinci Regency and Jambi Province.

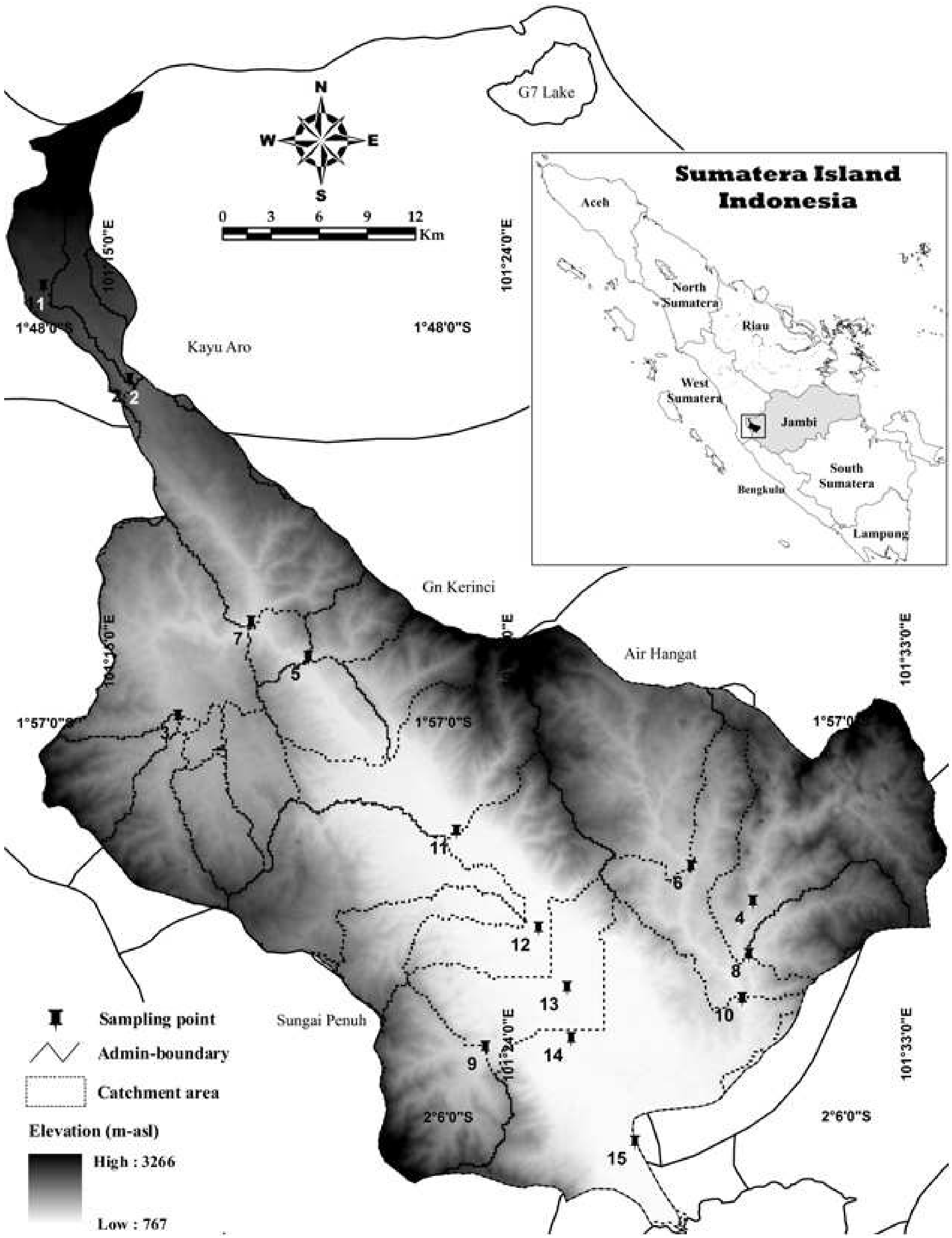


Figure 4.5. Overview of water quality sampling in Batang Merao Watershed, Indonesia

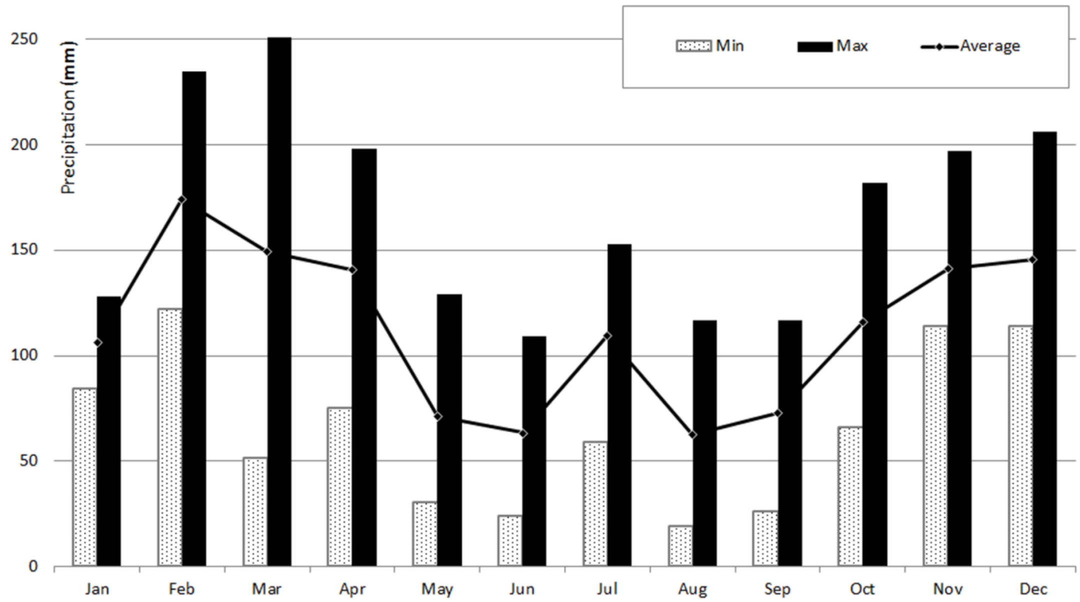


Figure 4.6. Seasonal variations of precipitation over the Batang Merao Watershed from 2000 to 2010

4.2.2.2 Materials

The basic data-sets required for this research are water quality data and land use data, as discussed below. For water quality data, water samples were collected from 15 stations or catchments within Batang Merao Watershed (Figure 4.5). Most of these stations distribute in the upper-middle-downstream area of Batang Merao Watershed. The primary data were collected from field survey on September 20, 2011 while the secondary data for the year 2006 and 2011 were obtained from the Environmental Management Agency of Jambi Province. The water quality parameters for this study were temperature physical data (TDS and TSS), chemical data (pH, DO, BOD, COD, P, and NO_3N), and biological data (Coliform).

For land use land cover data, Landsat image ETM data for the year of 2006 and 2011 (path 126/row 61) downloaded from the USGS Earth Resource Observation System were used in this study. For supporting image analysis, some ancillary data were used including ground truth data (83 samplings) acquired through the field survey (September 10-15, 2011), digital administrative map of Jambi Province provided by the Geo-spatial Information Agency of Indonesia, and digital watershed boundary map of Jambi Province published by the Ministry of Forestry of Indonesia. All the ancillary data were used to assist the training area in image classification and to collect the reference data in accuracy assessment.

4.2.2.3 Data analysis

The laboratory analyses of the water quality parameters were determined according to the standard of water quality status in Indonesia (Table 4.5)**.** In order to evaluate water quality status in the watershed, both Water Pollution Index (WPI) and STOrage and RETrieval (STORET) methods were used as they have been stated by Indonesian government through Environment Ministrial Decree No. 115/2003 (Ministry of Environment of Indonesia, 2003) and have been widely implemented by the Government of Jambi Province since 2007 (Jambi Provincial Government, 2007).

The WPI was utilized for assessing the degree of water environmental pollution and the integrative assessment of river water quality standard in the watershed. The WPI can be suggested for the decision maker or landscape manager to manage water quality status. The formulation of WPI is:

$$WPI_j = \sum_{i=1}^{n} \sqrt{\frac{(C_i / L_{ij})_M^2 + (C_i / L_{ij})_R^2}{2}} \qquad (4.1)$$

where C_i is the measured concentration of parameter *i*, L_{ij} is the permisible values *(PV)* for parameter *i* determined for water use *j*, and $(C_i/L_{ij})_{max}$ and $(C_i/L_{ij})_{ave}$ are maximum and average values of C_i/L_{ij} for water use *j*, respectively. The assessment of WPI can be followed by classification as follows

$0 \leq$ WPI ≤ 1.0 = Not Polluted (NP)

$1.0 <$ WPI ≤ 5.0 = Lightly Polluted (LP)

$1.0 <$ WPI ≤ 10.0 = Moderately Polluted (MP)

WPI >10.0 = Highly Polluted (HP)

Table 4.5 Selected parameters of water quality standard for river water in Indonesia

	No	Parameters	Unit	Water Quality Level			
				Class I	Class II	Class III	Class IV
Physical	1	Total Dissolved Solids (TDS)	mg/L	1,000	1,000	1,000	1,000
	2	Total Suspended Solids (TSS)	mg/L	*50*	*50*	*400*	*400*
Chemical	3	pH				6.5 – 9.0	
	4	Biological Oxygen Demand (BOD)	mg/L	*2*	3	*6*	6
	5	Chemical Oxygen Demand (COD)	mg/L	*10*	25	*50*	100
	6	Dissolved Oxygen (DO)	mg/L	*6*	4	*3*	0
	7	Phosphate (P)	mg/L	*0.2*	0.2	*1*	5
	8	Nitrate (NO_3N)	mg/L	10	10	20	20
Biological	9	*Coliform*	MPN/100 mL	1,000	5,000	10,000	10,000

adopted from:

1. Government regulation No. 82/2001 regarding the water quality management and water pollution control
2. Ministry of environment's Decree No. 115/2003 regarding the guidance of water quality status
3. The Jambi Governor regulation No. 20/2007 regarding regional water quality standard

In addition, the water quality level can be classified into 4 cateogries namely Class I for drinking water or any other use with the similar requirements; Class II for service water, recreational, gardening or any other use with the similar requirements; Class III for fresh water agricultural, farming and any other use with the similar requirements, and finally Class IV for irrigation and any other use with the similar requirements.

STORET method was used in order to evaluate water quality status for decision maker. It is also widely used by government and non–government agencies (Sholichin et al., 2010). The basic concept of STORET is to compare between water quality data and its standard. As a result, the status of water quality depends on the score of water sampling based on the following classification system:

0.0	=	Not Polluted (NP)
-1.0 to -10.0	=	Lightly Polluted (LP)
-11.0 to -30.0	=	Moderately Polluted (MP)
$\geq$ -30.0	=	Highly Polluted (HP)

A total of six LULC categories was considered in this study namely forest, mix plantation, tea plantation, shrub/bush, agricultural land, and settlement. This classification was modifed from LULC categories of Indonesian National Standar no. 7645:2010 by National Standard Agency of Indonesia which referred to the FAO's land cover classification system and ISO 19144-1 (BSN - National Standarization Agency of Indonesia, 2010). Supervised classification, the most widely used technique for quantitative analysis of remote-sensing image data (Sun et al., 2008, Pôças et al., 2011) , was used to perform image classification.

An accuracy assessment or confusion contingency matrix was implemented for evaluating the accuracy of the classified images. The error matrix compares the relationship between the known reference data (ground truth) and the corresponding results of an automated classification. The kappa coefficient, the value for estimation of how well remotely sensed classification accuracies to the reference data, was used for accuracy assessment (Jensen, 2004). Furthermore, All LULC data were analyzed in ERDAS version 8.1 and Arc GIS version 10.1.

A number of statistical tests were then performed with the LULC and water quality data. Descriptive statistics were used to analyze the basic characteristics of the data. Analysis of variance (ANOVA) was used to compare variations in water quality under different land uses with significance set at $p < 0.05$. Relationships among the considered variables were tested using Pearson's correlation with statistical significance set priori at $p < 0.05$. For further analysis of the relationship, the stepwise multiple regression analyses with water quality as dependent variable were carried out to assess the relationship between the land use composition in each part of the watershed. All of the statistical tests were performed in SPSS version 18.0 for Windows.

4.2.3 Result and Discussion

4.2.3.1 Water quality of Batang Merao watershed

The status of water quality in Batang Merau watershed had been evaluated based on the WPI method (Figure 4.7) and STORET method (Figure 4.8). Based on WPI analysis, most of the water quality observation stations (13 stations) were at the condition of lightly polluted (86.67%) and 2 stations were moderately polluted (13.33%). It can be observed from the graph that the average concentrations of some water quality parameters were already above the threshold (permissible values). For example, the average concentration of BOD was 5.0 mg/L beyond the PV (3.0 mg/L); the average concentration of DO was 4.21 mg/L beyond the PV (4.0 mg/L), and the average concentration of P was 0.31 mg/L beyond the PV (0.20 mg/L).

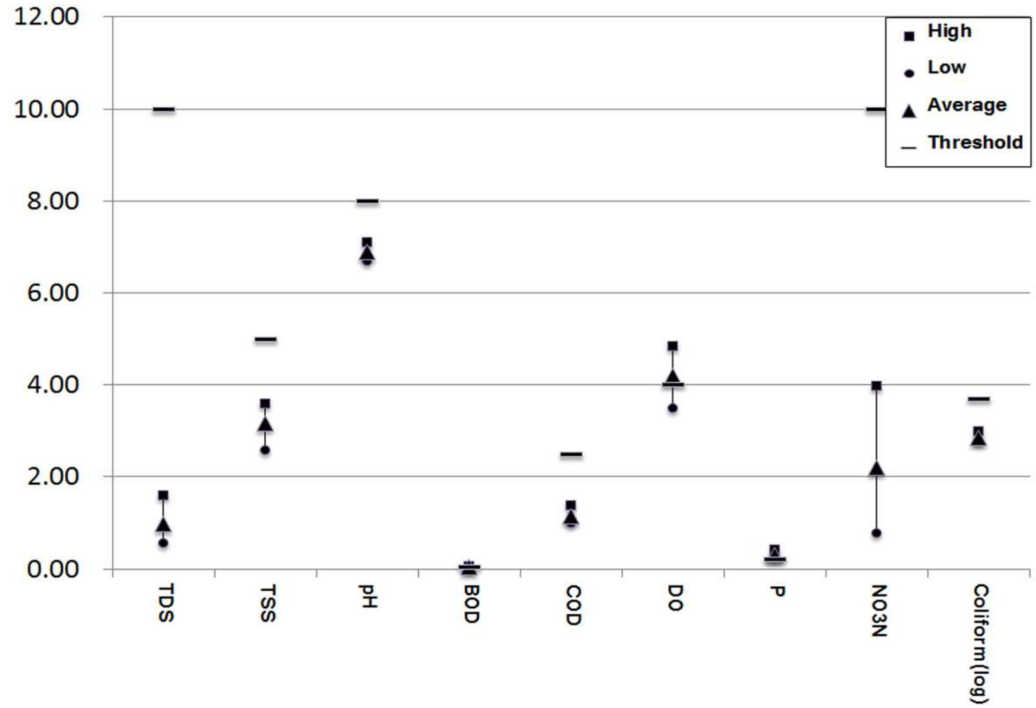


Figure 4.7. The standardized water quality status of WPI method in Batang Merao Watershed

Conversely, based on STORET method, most of the stations (12 stations) were at the condition of moderately polluted (80.00%) and 3 stations (20.00%) were lightly polluted. The different result between the two methods could happen because of different principles of data input in calculation (Sholichin et al., 2010). The combination of these two methods was related to the final assessment of the watershed served in Table 4.6.

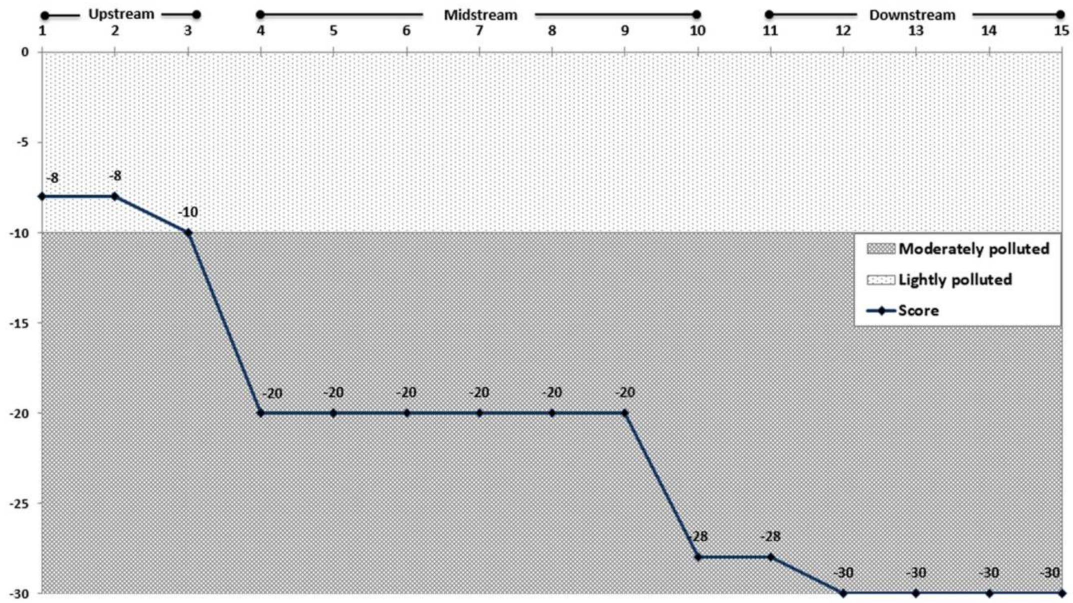


Figure 4.8. Water quality status of STORET method in Batang Merao Watershed

As previously discussed, the status of water quality in Batang Merau watershed in general was at category “B” (river water category). However, based on the combination assessment of WPI and STORET, only the upstream can be classified as “B”. Meanwhile, the midstream might be lowered into “C”, along with the downstream which had been in the category.

Table 4.6. Resume of water quality status using WPI and STORET methods in Batang Merao Watershed

Station	Type	WPI Method		Storet Method		Class Determination	
		Value	Status	Score	Status	Base on Current Regulation	Base on Analysis
1	Upstream	1.28	LP	-8.00	LP	B	B
2	Upstream	1.23	LP	-8.00	LP	B	B
3	Upstream	1.29	LP	-10.00	LP	B	B
4	Midstream	2.42	LP	-20.00	MP	B	B/C
5	Midstream	2.53	LP	-20.00	MP	B	B/C
6	Midstream	2.54	LP	-20.00	MP	B	B/C
7	Midstream	2.58	LP	-20.00	MP	B	B/C
8	Midstream	3.58	LP	-20.00	MP	B	B/C
9	Midstream	3.66	LP	-20.00	MP	B	B/C
10	Midstream	3.70	LP	-28.00	MP	B	B/C
11	Downstream	3.72	LP	-28.00	MP	B	B/C
12	Downstream	3.75	LP	-30.00	MP	B	B/C
13	Downstream	4.34	LP	-30.00	MP	B	B/C
14	Downstream	5.21	MP	-30.00	MP	B	C
15	Downstream	5.62	MP	-30.00	MP	B	C

Table 4.7. Summary of LULC at different periods in Batang Merao waterhshed

LULC	2006		2011		Change		Average rate of change	
Classsification	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)/yr	%/yr
forest	16,425.48	24.20	12,304.79	18.13	-4,120.69	-25.09	-412.07	-2.51
mix plantation	19,977.76	29.43	24,034.57	35.41	4,056.81	20.31	405.68	2.03
tea plantation	1,070.08	1.58	989.68	1.46	-80.39	-7.51	-8.04	-0.75
shrub/bush	15,432.46	22.74	14,452.70	21.29	-979.76	-6.35	-97.98	-0.63
agricultural land	13,454.08	19.82	14,457.84	21.30	1,003.76	7.46	100.38	0.75
settlement	1,514.62	2.23	1,634.89	2.41	120.27	7.94	12.03	0.79
	67,874.48		67,874.48					

4.2.3.2 Dynamics of LULC of Batang Merao watershed

As summarized in Table 4.7, there was a decrease in forest, tea plantation, and shrub/bush by 25.09%, 7.51%, and 6.35%, respectively. On the other hand, there was an increase in mix plantation, agricultural land, and settlement by 20.31%, 7.46%, and 2.41%, respectively. The distribution pattern of LULC in Figure 4.9 showed that the most areas of the watershed were covered by mix plantation (35.00%), forest (24.00%), shrub/bush (21.00%), and agricultural land (17.00%).

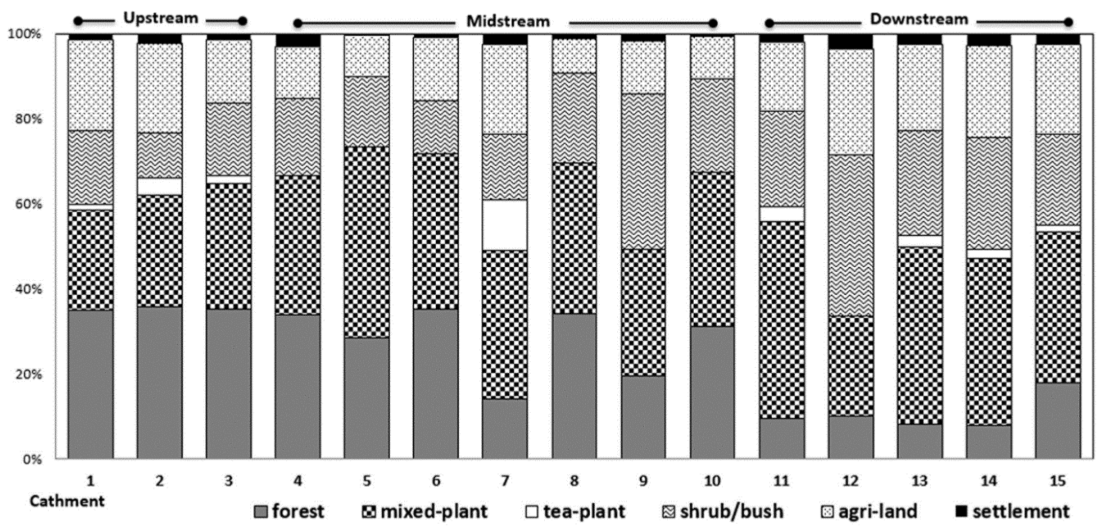


Figure 4.9. LULC gradients in the 15 monitoring catchments in 2011

In general, the patterns showed a tendency towards more land being brought under mix plantation and agricultural land. These given data expressly stated that the increase in cultivated function resulted in deforestation, meaning that some forest areas (protected areas were removed and converted to cultivated areas, such as mix plantation, paddy-field, and potato plantation.

4.2.3.3 The relationship between land use land cover and water quality

The statistical test of One-way Anova in Table 4.8 revealed differences with regard to both land cover and water quality among the upstream, midstream, and downstream of the watershed. As summarized in Table 4.9, the result of Pearson's correlation analysis indicated that LULC types were significantly correlated with some water quality parameters. For example, mix plantation showed a significant positive correlation with BOD and COD by 0.922 and 0.646, respectively.

Table 4.8. One-way Anova among parameters and watershed types in Batang Merao watershed

			Mean square	F	Sig
Difference among parameters	TSS	Between groups	22.000	3.578	<0.001
		Within groups	6.148		
	BOD	Between groups	1.648	3.958	<0.001
		Within groups	0.414		
	COD	Between groups	2.121	8.355	<0.001
		Within groups	0.254		
	DO	Between groups	0.494	4.481	<0.001
		Within groups	0.102		
	P	Between groups	0.004	2.556	<0.001
		Within groups	0.002		
Difference among watershed types (Upstream, Midstream, and Downstream)	TSS	Between groups	155.589	27.925	<0.001
		Within groups	5.572		
	BOD	Between groups	11.813	31.49	<0.001
		Within groups	0.376		
	COD	Between groups	15.278	53.218	<0.001
		Within groups	0.287		
	DO	Between groups	3.713	40.691	<0.001
		Within groups	0091		
	P	Between groups	0.023	15.826	<0.001
		Within groups	0.001		

The negative correlation was shown between agricultural land and BOD (-0.67) and between settlement and BOD (-0.594). These results suggested that local expansion of mix plantation, agricultural land, and settlement could be the primary driving forces of BOD and COD parameters.

Table 4.9. Pearson's correlation coefficient between LULC and water quality parameters

	F	MP	TP	S/B	AL	S
TSS	-.234	.680	-.187	.148	.415	-.356
BOD	-.201	**.922**	-.377	.369	**-.670**	**-.594**
COD	-.206	**.646**	-.119	-.082	-.295	-.181
DO	.174	-.379	.024	.148	.108	.038
P	-.320	.318	-.080	-.255	.067	.129

Note: $p<0.05$ (Bold)
Water quality parameters are: TSS, BOD, COD,DO, and P
LULC types are: F (forest), MP (mix plantation), TP (tea plantation), S/B (Shrub/Bush), AL (agricultural land), and S (Settlement)

Only water quality parameters in the upstream (2 parameters) and downstream (5 parameters) could be estimated since only in those locations the regression model was significant (Table 4.10). In the upstream case, the COD predicators were forest, mix plantation, and agricultural land while the BOD predicators were mix plantation, agricultural land, and settlement. In the downstream case, there were similar predicators for the TSS, COD, BOD, and DO parameters, namely forest, mix plantation, and agricultural land. Meanwhile, the P predicators in this segment were mix plantation, agricultural land, and settlement. Tong and Chen (2002) conclulded that there was a significant relationship between land use and river water quality.

Table 4.10. Stepwise regression for water quality parameters and LULC in Batang Merao watershed

	Dependent	Independent	Equation	R^2
Upstream	COD	F, MP, AL	COD = 8.54+2.82F+1.48MP+1.88AL	.714
	BOD	MP, AL, S	BOD = 2.10+1.83F-1.06MP+46.46AL	.665
Midstream	Insignificant			
Downstream	TSS	F, MP, AL	TSS =10.92+16.85F+25.52MP+56.80AL	.596
	COD	F, MP, AL	COD = 5.12+5.91F+7.34MP+20.25AL	.710
	BOD	F, MP, AL	BOD = -2.99+3.96F+6.90MP+13.67AL	.687
	DO	F, MP, AL	DO = 6.74–2.26F–3.22MP-7.18AL	.539
	P	MP, AL, S	P = 0.158+0.29MP+0.34AL+0.07S	.516

Note: significance at 0.05 probability level (p = 0. 05)

From this regression analysis, it was found that forest, mix plantation, and agricultural land were the three main predicators affecting the changes of some parameters of the water quality in the watershed. This result was in line with other studies finding that the water quality in a watershed was determined by forest condition (Dessie and Bredemeier, 2013) dan agriculture (Zampella et al., 2007) particularly in the tropical landscape (Uriarte et al., 2011). Furthermore, Huang *et al* (2013) concluded that the cultivated land plays a complicated role in influencing the water quality.

4.2.4 Conclusion

This study showed the condition of Batang Merao watershed as a representative of tropical watersheds facing the LULC changes which affected the water quality. In this case, WPI and STORET methods could be used for evaluating the status of water quality effectively. To evaluate the humid tropical watershed like Batang Merao Watershed, it is strongly recommended to use the methods periodically.

In this study, LULC types showed a significant relationship with water quality parameters. Some water quality parameters, like TSS, COD, BOD, DO, and P, were predicted by using regression models on land use indicators. It was noticed that mix plantation, agricultural land, and forest were the most important parameters to predict water quality parameters. Deforestation due to agricultural activities (expansion of plantation, paddy field, and potato) and increasing demand for settlement imposed threat on water quality degradation. Furthermore, it could be concluded that water quality degradation in the Batang Merao watershed was associated with LULC, which were generally good predicators of water quality conditions.

Since this study can help people to better understand LULC status, water quality, and their relationship, LULC should be well managed and some conservation programs should be taken in order to minimize the potential impact on water quality.

Chapter 5

Land use and land cover change and its ecological impact in West Java, Indonesia (*a comparative study*)

In any discussions of watershed and land development in Indonesia, an important distinction should be compared between Java and the Outer Islands (Sumatera, Borneo, Sulawesi and Papua Islands). The significant reasons for this comparative study on this topic are;

1. Practically all of Indonesia's forests are located in the outer islands. Only vestigial forest areas remain in Java which has the highest population density in Indonesia. Most remaining forests on Java are located in the uplands and have been designated as protection forests.
2. It is well known that because of the economic development and the vulnerable ecology and the environment, Java's environment is also under increasing pressure (Pagiola, 2000). Land use is rapidly changing in Java and there has been concern over increased frequency and intensity of floods and soil erosion (Agus et al., 2004).
3. By comparing the LULC problem in Java and Sumatera, it will be understood the problem solving from others.

Prioritization can be used to identify area of conservation in the wider landscape context (Gordon et al., 2009). Of course, priority determination on handling land degradation in Indonesia becomes more important. In the past, a rehabilitation program for land degradation by the government did not achieve expected land improvement; on the contrary, land degradation becomes more increase than land rehabilitation ability.

5.1 Introduction

Change in LULC is increasingly recognized as an important driver of environmental change on all spatial and temporal scales (Turner et al., 1994) and it can be a major threat to biodiversity (Verburg et al., 1999). LULC is always dynamic when it constantly changes in response to the dynamic interaction between underlying drivers and proximate causes (Lambin et al., 2003). Globally, LULC today is altered principally by direct human use, such as agriculture and livestock raising, forest harvesting and management, and urban and suburban construction and development (Lambin et al., 2003). Landscape changes include not only damage by agriculture, but also the degradation of historic value and land conservation functions (Ohta and Nakagoshi, 2011).

During the last few decades, watershed degradation has been seen as a serious threat to environmental conditions. Many of watersheds today suffer from several detrimental problems such as severe soil erosion, flood, drought, and declining land productivity or land degradation. Land degradation, a synonym for soil degradation (Kertész, 2009) that its functions have damaged by climate or human activities (Maitima et al., 2009), is a critical environmental problem in many countries

(Ouyang et al., 2010) and a widespread problem in developing countries (Ananda and Herath, 2003). About 85% of land degradation in the world is associated with soil erosion (Oldeman et al., 1991) such as in South America averaging 30–40 ton ha^{-1} y^{-1} (Barrow, 1991), in the Citarik, West Java 94–103 ton ha^{-1} y^{-1} (Kusumandari and Mithcell, 1997) in Sinchuan China about 80–120 ton ha^{-1} y^{-1} (Tomic, 1998).

The theoretical framework of human population pressure has been used when estimating land degradation (Barbier, 1997; Holden and Sankhayan, 1998; Ramaswamy and Sanders, 1992; Verburg et al., 1999; Wang et al., 2010). The theory behind it is that as the population increase and limited land resource. Problems arose when the population started to increase, and the pressure on land resources became more severe. The result is small farms, low production and increasing landlessness or land shortage. Land shortage and poverty, taken together, lead to unsustainable land management practices, the direct causes of degradation. (FAO, 1990).

Therefore, it is very useful to planners and policy makers initiating remedial measures and for prioritizing soil degradation (Rahman et al., 2009). Prioritization can be used to identify the area of conservation in the wider landscape context (Gordon et al., 2009). Of course, priority determination on handling land degradation in Indonesia becomes more important. In the past, rehabilitation program by the government did not achieve expected land improvement; on the contrary, land degradation becomes more increase than land rehabilitation ability. The priority will be considered because it can show the priority of land degradation in the watershed. It is also useful for handling choices if there are limitations such as rehabilitation financing, infrastructure, time and labors. In order to strengthen the conservation and protection of the ecological environment, comprehensive planning is necessary with considerations that include balancing the social, safety, ecology and landscape and treating the whole watershed as a unit (Wu and Feng, 2006). In addition, to understand landscape change, especially the loss of traditional and cultural landscapes, it is necessary to integrate social, economic and ecological aspects (Ohta and Nakagoshi, 2011).

The area, Cirasea sub-watershed, was selected for this research mainly because it is one of the most important sub-watersheds of Citarum watershed, a main source of water and protected area in West Java. Cirasea subwatershed has a prominent role as a conservation area and buffer zone of ecosystem in relation to other regions. The risk impact of land degradation in Cirasea subwatershed will affect downstream areas such as Bandung city and Karawang regency. In addition, it had undergone substantial land use and land cover change and it was subject to high population pressure.

The main purpose of this study was to analyze changes in LULC and to determine the priority on handling the land degradation in Cirasea sub-watershed. The findings in this study might help our understanding of LULC change, population pressure and handling land degradation. In brief, the targets of this study were to determine (i) LULC change in two different years between 2003 and 2010. (ii) land degradation, (iii) population pressure, (iv) the priority on handling the land degradation based on the combination between two different aspects of (ii) and (iii).

5.2 Material and methods

5.2.1 Description of study area

The study area, in West Java province, consisted of approximately 34,458.06 ha located latitudes 6°59'–7°14' south and longitudes 107°3' –107°48' east (Figure 5.1). This region covers seven sub regencies and 58 villages. It is situated in a tropical zone that the annual precipitation rate ranges from 2,089 mm y^{-1} during the last 20 years. The annual mean temperature is 24.10℃ ; the relative humidity is 94.9% during the last 10 years. The soil structure is dominated by Andosol and Latosol.

In Cirasea subwatershed, agriculture is dominant activity whole the year that tea plant and rice as prime products. At least 61% of people work in agriculture sector and 45.9% of the land use is agriculture field. The population of this area was 468,602 in 1999 and 571,445 in 2010.

5.2.2 Methods

The study used Landsat image data, Aster Digital Elevation Model (Aster-DEM), climate data, soil data, ground check data and secondary data of the study area supported by interview and questionnaires. (Table 5.1)

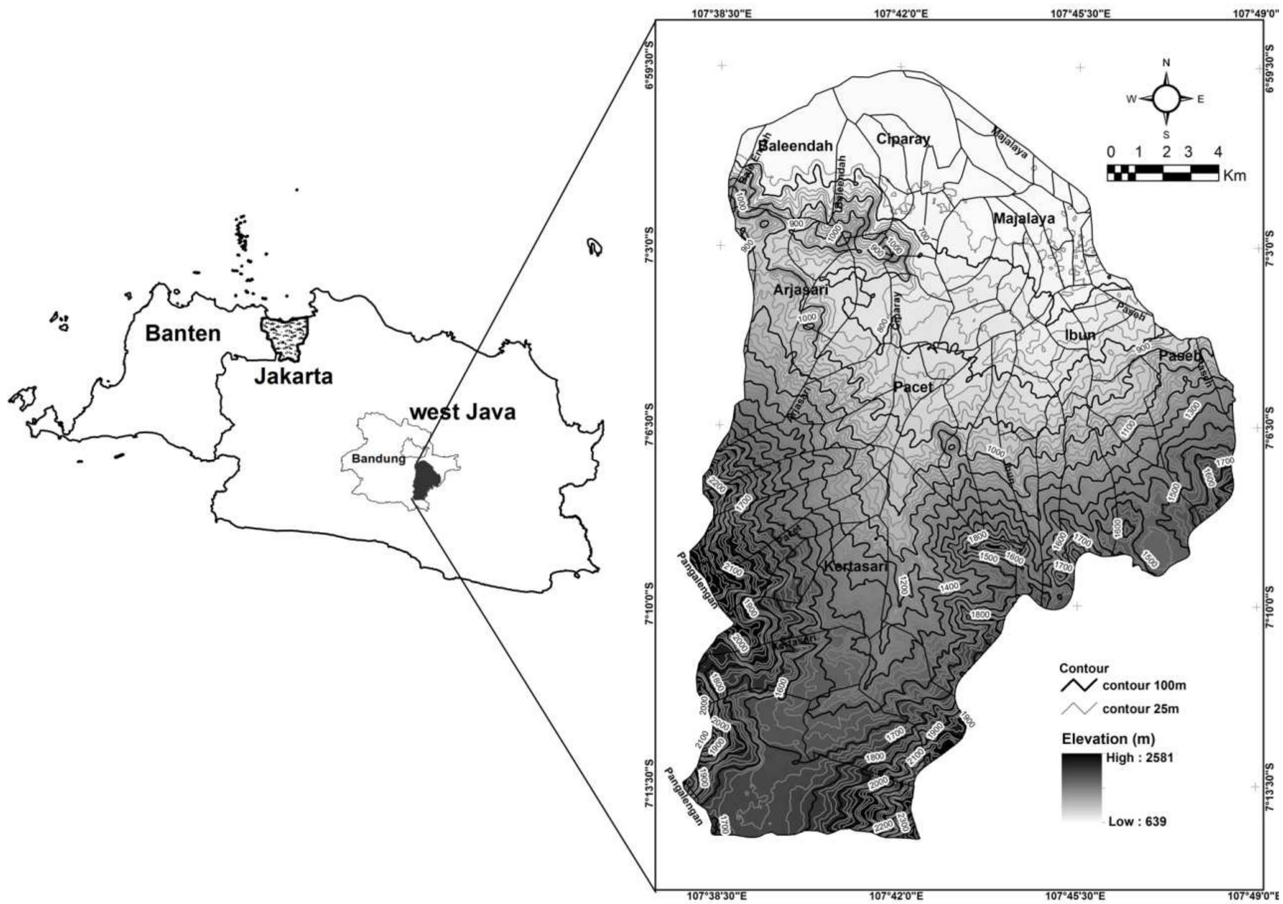


Figure 5.1. Location of Cirasea sub-watershed s howing the elevation at 25m contour intervals

Table 5.1 Data description and collection

for analysis of LULC change in Cirasea sub-watershed

Data	Description	Source
Landsat ETM	Path 122 / row 65 July 24, 2010 and May 18, 2003	http://glovis.usgs.gov/
DEM	Aster GDEM 30 m	http://demex.cr.usgs.gov/
Soil series map	Soil type	Development planning board of Bandung Regency (Bappeda)
Rainfall	Monthly rainfall and distribution	
Land use planning map	Regional land use planning 2000-2010	
Population	Growth, ratio, distribution 2003-2010	Statistics office of Bandung Regency
Socio-economic	basic need, landhold, agricultural and non income 2003-2010	116 Respondents/ primary survey

Figure 5.2 shows a general framework involved in the LULC change and priority determination on handling the land degradation. This research began by analyzing LULC change as input for crop management and conservation (CP) factor in USLE context. In this step, we also analyzed the potential erosion level using USLE method and the population pressure index using PPI method in the study area. Second step was to design scenario of priority determination using rank sum method.

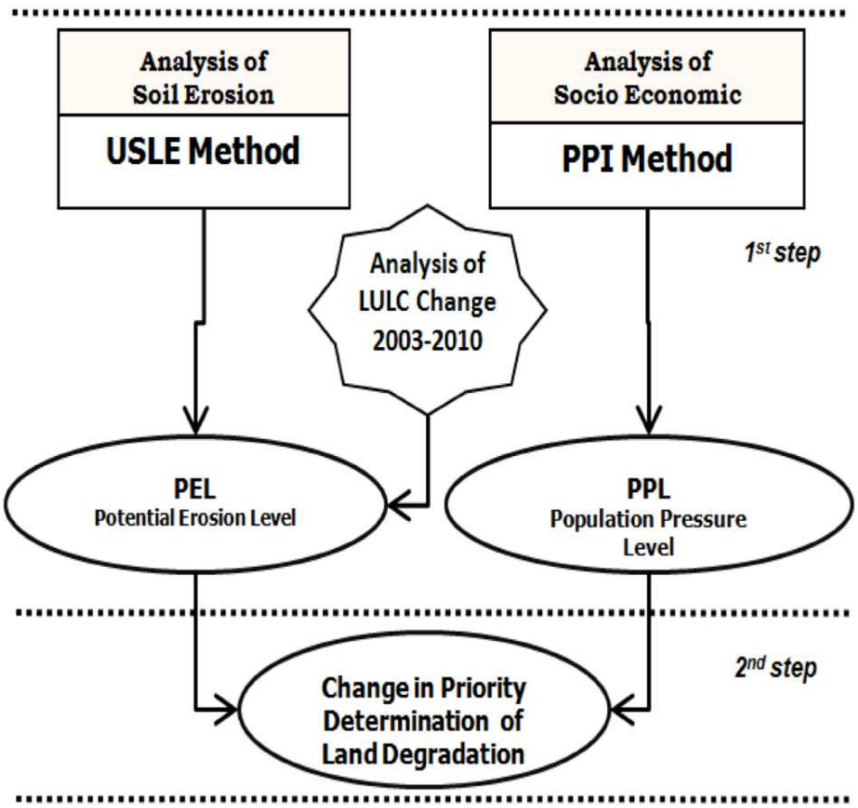


Figure 5.2. Steps involved in the proposed method of this research

All steps were conducted using GIS tools (ArcGIS 9.3.1) and Remote Sensing tools (Erdas Imagine 8.7). Furthermore, to investigate socioeconomic data, village as the lowest socioeconomic administrative level was used for unit of analysis. Because of the dynamic and of planning and policy decision, it is important to propose the priority determination.

Supervised classification, the most common and widely used classification (Chandola and Vatsavai, 2010; Diallo et al., 2009; Pôças et al., 2011) was used to perform image classification. Confusion matrix change, the most common method for assessing remote sensing data accuracy (Congalton, 1991), and the kappa coefficient, the value for estimation on how well remotely sensed classification accurate to the reference data (Jensen, 2004), were used for accuracy assessment. The Kappa (Khat) statistics was guided by the equation 2.1 (see chapter 2 pp 55).

The potential soil erosion was determined by using the USLE method (Palma et al., 2007; Wischmeier and Smith, 1978)and which can be described using equation 2.3 (see chap 2 pp 52).

The population pressure level was determined by using the PPI method (Ministry of Forestry of Indonesia, 2004, 2013; Soemarwoto, 1985). The index of population pressure is calculated as equation 2.2 (see chapter 2 pp 56). Otherwise, if the PPI is more than one, there is population pressure to land that exceeds land capacity for agricultural activity.

In order to determine priority of different scale measurement and criteria of potential soil erosion and population pressure that their raw scores cannot compare them, it is essential to use standardization of multi-criteria analysis. The rank sum method was selected for this study where it is based on a pair-wise comparison matrix. The method is one of the simplest criterion weighting techniques though criticized for its lack of theoretical foundations in interpreting the level of importance of a criterion (Saaty, 1977). It is selected here for being a straightforward method that can be used with least confusion to the decision makers. Relative weights were assigned to the factors, using the straight rank-sum method as explained in equation 5.1:

$$wj = \frac{(n - rj + 1)}{\sum (n - rk + 1)} \quad (5.1)$$

where wj is the normalized weight for j factor, n is the number of factors under consideration (when k = 1, 2, n) and rj is the rank position of the factor.

5.3 Results

5.3.1 Land use and land cover change 2003–2010

To derive the land use/land cover map in the period of 2003–2010, five LULC categories have been identified such as forest, plantation, mixed plantation, grassland, paddy field, and settlement that were adopted from LULC classification of the Ministry of Forestry of Indonesia published in 2000. Generally, there was a continuous LULC change-taking place for the most LULC types in the past seven years. The LULC classes for Cirasea sub-watershed as shown in Table 5.2 and the LULC map as shown in Figure 5.3 helps to understand for the LULC change. In addition, the comparison of the LULC change area values and area percentage from 2003 to 2010 were summarized.

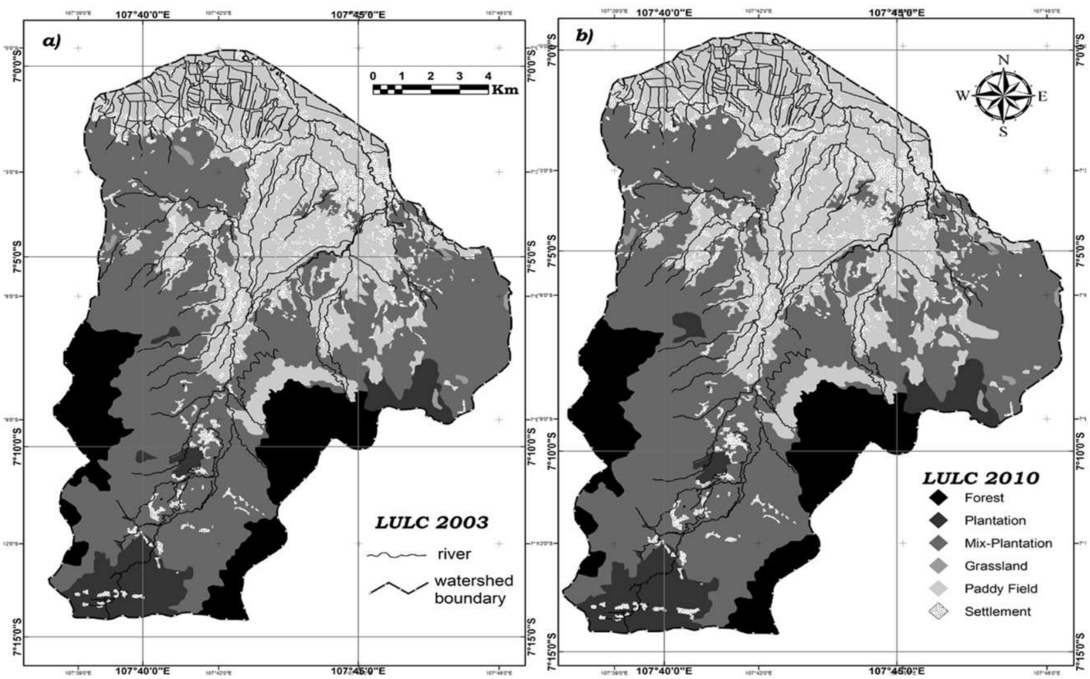


Figure 5.3. Land use and land cover maps in Cirasea sub-watershed from a) 2003 to b) 2010

Table 5.2. Distribution of LULC change between 2003 and 2010

LULC Classification	2003		2010		Change 2003-2010		Average rate of change	
	Ha	%	Ha	%	Ha	%	ha/yr	%
Forest	4,172.9	12.11	3,925.7	11.39	-247.26	-5.93	-35.32	-0.85
Grassland	131.0	0.38	97.5	0.28	-33.49	-25.57	-4.79	-3.65
Mix-Plantation	16,327.2	47.39	16,338.0	47.42	10.8	0.07	1.54	0.01
Paddy Field	9,002.8	26.13	9,114.7	26.45	111.8	1.24	15.97	0.18
Settlement	2,781.9	8.07	2,929.1	8.50	147.3	5.29	21.04	0.76
Plantation	2,040.3	5.92	2,051.1	5.95	10.9	0.53	1.55	0.08
Total	34,456.1	100.00	34,456.1	100.00				

Table 5.3**.** LULC changes matrix in Cirasea watershed between 2003 and 2010

		LULC 2010 (ha)						Total
		F	**G**	**MP**	**PF**	**S**	**TP**	
LULC 2003 (ha)	Forest (**F**)	***3,925.68***		247.26				4,172.94
	Grassland (**G**)		***97.50***	33.50				131.00
	Mix-Plantation (**MP**)			***15,991.44***	178.73	78.00	78.98	16,327.15
	Paddy Field (**PF**)				***8,933.77***	69.07		9,002.84
	Settlement (**S**)			19.79	2.15	***2,759.94***		2,781.88
	Tea Plantation (**TP**)			45.97		22.14	***1,972.16***	2,040.27
	Total	3,925.68	97.50	16,337.96	9,114.65	2,929.15	2,051.15	***34,456.08***
	Net change 2003-2010	-247.26	-33.50	10.80	111.81	147.26	10.88	
	Change in %	-5.93	-25.57	0.07	1.24	1.64	0.53	

Table 5.4. Accuracy assessment for supervised classification of LULC for 2010

Classification	Reference Data							
	F	**G**	**MP**	**PF**	**S**	**TP**	**Total**	**User's Accuracy (%)**
Forest (**F**)	**3**		1				4	75.00
Grassland (**G**)	1	**0**	1				2	0.00
Mix-Plantation (**MP**)		1	**19**	1	1		22	86.36
Paddy Field (PF)		1	3	**18**	1		23	78.26
Settlement (**S**)			1	2	**14**		17	82.35
Tea Plantation (**TP**)					1	**4**	5	80.00
Total	4	2	25	21	17	4	73	Overall Accuracy **79.45%**
Producer's Accuracy (%)	75.00	0.00	76.00	85.71	82.35			Kappa coefficient **0.65**

According to the results of the LULC change matrix from 2003 to 2010, it is clearly shown in the matrix (Table 5.3). The changes of the most LULC go to the final LULC destination mostly for paddy field, settlement, and plantation. For instance, the majority LULC types including forest and grassland converted to LULC type dominantly to paddy fields and settlement.

The accuracy of LULC change along with the overall accuracy and the Khat coefficient was summarized in Table 5.4. The overall accuracy of classification image was 79.45% and the Kappa coefficient was 72.53%. The producer's accuracies of all classes were consistently high, ranging from 75% to 86.36%, with an exception of the grassland. The user's accuracies for all the classes were precisely high, ranging between 75% and 85.71% respectively, also with an exception of the grassland.

The LULC classification results are summarized for the years 2003 and 2010 in Table 5.2 and Figure 5.3. From 2003 to 2010, the area of mixed plantation, paddy field, settlement and tea plantation increased 10.8 ha (0.07%), 111.8 ha (1.24%), 147.3 ha (5.29%) and 10.9 ha (0.53%) respectively. On the other hand, forest and grassland decreased 247.26 ha (5.93%) and 33.49 ha (25.57%) respectively. In general, the patterns showed a tendency towards more land being brought under annual crops and settlement. These given data expressly state that the increase in agricultural areas (cultivated function) mostly result in deforestation which means some forest areas (protected areas) were removed and converted to cultivated areas such as plantation and paddy-field.

5.3.2 Change in potential soil erosion

Table 5.5 and Figure 5.4 show the clear pattern of changes characterized by erosion potential category. However, there is a net increase in the total under the very high, high and moderate level by 0.88%, 0.78% and 4.47% respectively. At the same time, the area under low and very low level is decreased by −3.14% and −2.99% respectively which is a major potential soil erosion. In 2003, the area has clear levels of soil loss that vary from about 2.6 ton ha^{-1} yr^{-1}, the lowest, to 174.4 ton ha^{-1} yr^{-1}, which is the highest. In 2010, the area has clear levels of soil loss that vary from about 4.8 ton ha^{-1} yr^{-1}, the lowest, to 199.4 ton ha^{-1} yr^{-1}, which is the highest.

In order to better understanding of the population pressure to land, the population pressure index was examined in the year 2003 and 2010 that summarizes in Table 5.6. The data indicated that Cirasea sub-watershed was dominated by very high population pressure area which is increased by 30,332.42 ha (88.03%) in 2003 and 31,637.65 ha (91.82%) in 2010 respectively. However, the lowest PPI is 0.11 to 0.78 in Manggungharja village where the highest PPI was 4.58 to 6.41 in Cikawao village to Nagrak village.

Table 5.5. Potential soil erosion in Cirasea sub-watershed

Potential soil erosion level	Soil Loss Range (ton $ha^{-1}yr^{-1}$)	2003		2010		Change 2003-2010	
		area (ha)	%	area (ha)	%	area (ha)	%
very high	>60	15,134.81	43.92	15,267.81	44.31	133.00	0.88
high	30-60	8,996.26	26.11	9,114.95	26.45	118.69	0.78
moderate	10-30	3,324.54	9.65	4,000.66	11.61	676.12	4.47
Low	5-10	2,364.40	6.86	1,888.74	5.48	-475.66	-3.14
very low	<5	4,636.07	13.46	4,183.92	12.14	-452.15	-2.99
Total		34,456.08	100.00	34,456.08	100.00		

Table 5.6. Population pressure level of Cirasea sub-watershed

Population Pressure Level	year	Area		Population Pressure Index		
		(ha)	%	The lowest Index	The highest Index	Average
No Population pressure	2003	4,123.66	11.97	-	-	-
	2010	2,818.43	8.18			
Population Pressure	2003	30,332.42	88.03	0.11 Manggungharja	4.58 Cikawao	4.12
	2010	31,637.65	91.82	0.78 Manggungharja	6.41 Nagrak	6.08

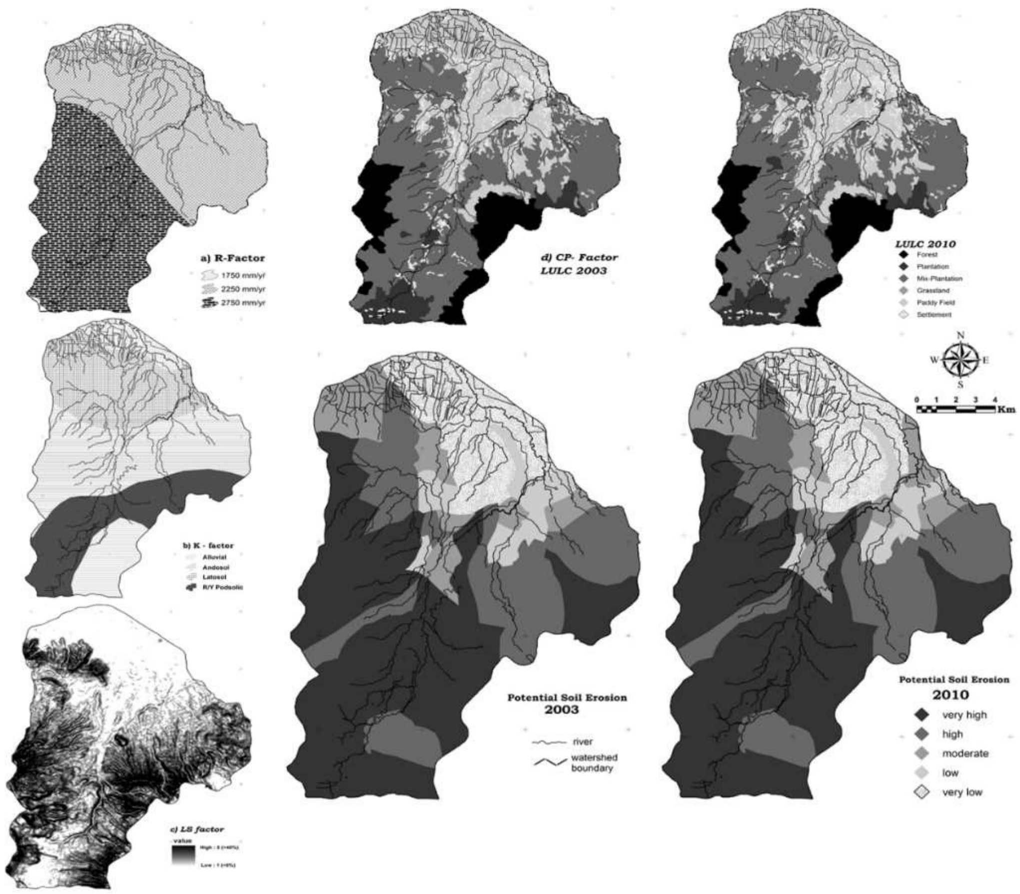


Figure 5.4. The process of combining USLE factors for determining soil erosion a) R-factor, b) K-factor, c) LS-factor, d) CP-factor and e) A – potential erosion level

5.3.3 Change in priority determination on handling land degradation

The change in priority determination on handling land degradation from 2003 to 2010 is shown in Figure 5.5 and Table 5.7. The results showed the priority associated with the combination between soil erosion and population pressure set in the beginning of the analysis as priority 1,2, 3, 4 and 5. A clear change can be seen in those priorities from 2003 to 2010 where a net decrease in the total under priority 4 and 5 by −11.94% and −0.57% respectively. On the contrary, the area under priority 1, 2 and 3 is increased by 0.14%, 4.21% and 8.16% respectively, which is the major priority determination on handling land degradation.

Table 5.7. Priority on handling land degradation between 2003 and 2010

Priority	2003		2010		change 2003-2010	
Determination	area (ha)	%	area (ha)	%	area (ha)	%
Priority-1	15,865.76	46.05	15,888.25	46.11	22.49	0.14
Priority-2	8,720.27	25.31	9,387.78	27.25	667.51	4.21
Priority-3	3,235.58	9.39	4,530.58	13.15	1,295.00	8.16
Priority-4	5,258.98	15.26	3,363.98	9.76	-1,895.00	-11.94
Priority-5	1,375.49	3.99	1,285.49	3.73	-90.00	-0.57
	34,456.08	100.00	34,456.08	100.00		

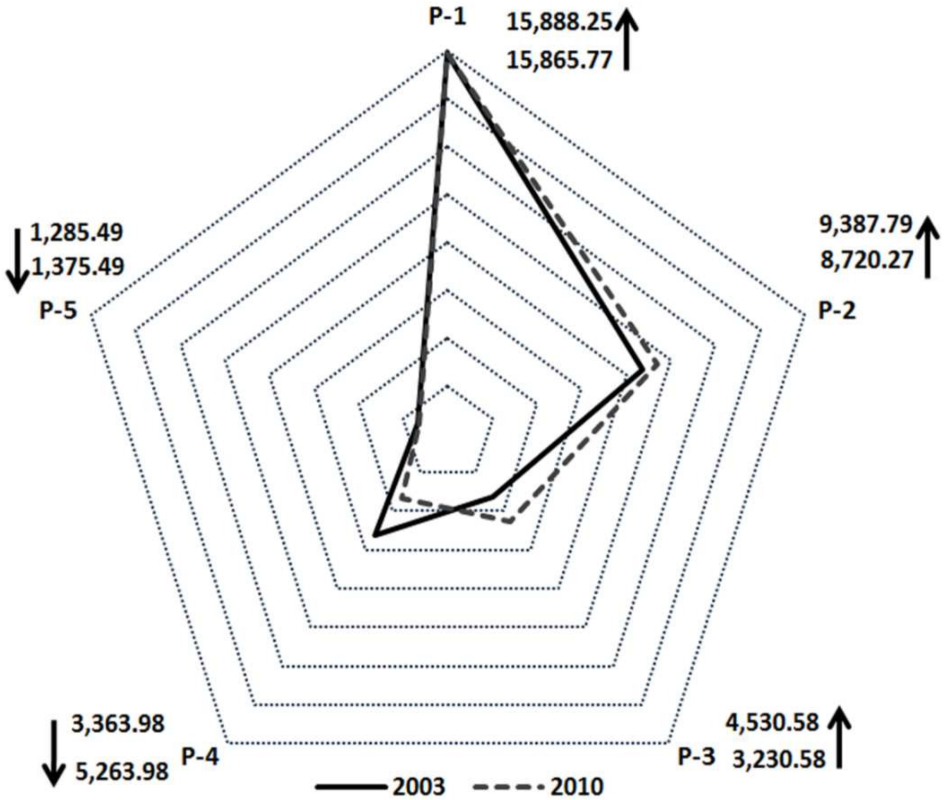


Figure 5.5. The pattern of priority determination change
on handling land degradation

5.4 Discussion

There are many factors, which trigger priority determination on handling land degradation such as LULC change, soil erosion and population pressure. Although the biophysical aspects such as rainfall, soil type, topography and LULC determine mostly the spatial pattern of soil erosion and its changes, the population pressure parameters such as population growth, agricultural income and landhold and LULC change have the key role in creating a priority on handling land degradation.

The results of LULC changes give the general information of the major changes of the LULC classes analyzed for the two periods. Varying magnitudes of change have been recognized over the study period. Some LULC categories increased and thus have positive mean rate of change but others were diminished and thus have negative rate of change. The changes of natural land resources such as forest and grassland were decreasing but cultivated land resources such as paddy-field, settlement and plantation were expanding. The rate of change of settlement indicates an ever expanding in the positive direction with rapid population growth from the escalation of settlement area by 5.29%. On the other hand, the rate of change of grassland and forest confirms this land conversion was clearly showed 25.57% and 5.93% respectively.

This study showed high potential soil erosion areas, which were indicated by the average annual soil loss about 86.50 ton ha^{-1} yr^{-1} in 2003 and increased to 96.8 ton/ha/yr in 2010. This is the indicator of the existence of the risk of soil erosion in Cirasea sub-watershed. Furthermore, to better understanding of the high level of Cirasea sub-watershed can be explained by USLE parameters such as erosivity, erodibility, slope and LULC factor.

The values of all USLE parameters in this area were very high. Erosivity as an energy source of soil erosion was very high with the annual mean is about 3,810.1 mm yr^{-1}. Cirasea sub-watershed is dominated by very sensitive soil erodibility such as Andosol, Alluvial, and red/yellow Podsolik. The slope factor is also influenced the potential soil erosion that more than 24,304 ha (70.54%) of this area is covered by area with slope more than 25%. Moreover, among them, the values of LULC factor were dynamics timely and increased the total value and the level of potential soil erosion in this area.

The study results strongly show that the population pressure in this area was very high as shown in Table 5.6. The main causes of this can be explained by the parameters of population pressure such as population growth, landhold and contribution of agricultural income. Figure 5.6 shows that population growth and population density of this area are very high that can cause the need of land resource for agricultural activity and settlement. As soon as population growth and density, they need to clear the forest area and to engage in agricultural activities (Drigo 1999). Furthermore, the range of average agricultural landhold was between 0.10 ha to 1.00 ha and it was not enough for farmers to fulfill the basic need of their family. Figure 5.7 shows the income contribution of two different sectors that was dominated by agriculture sector (63.97%).

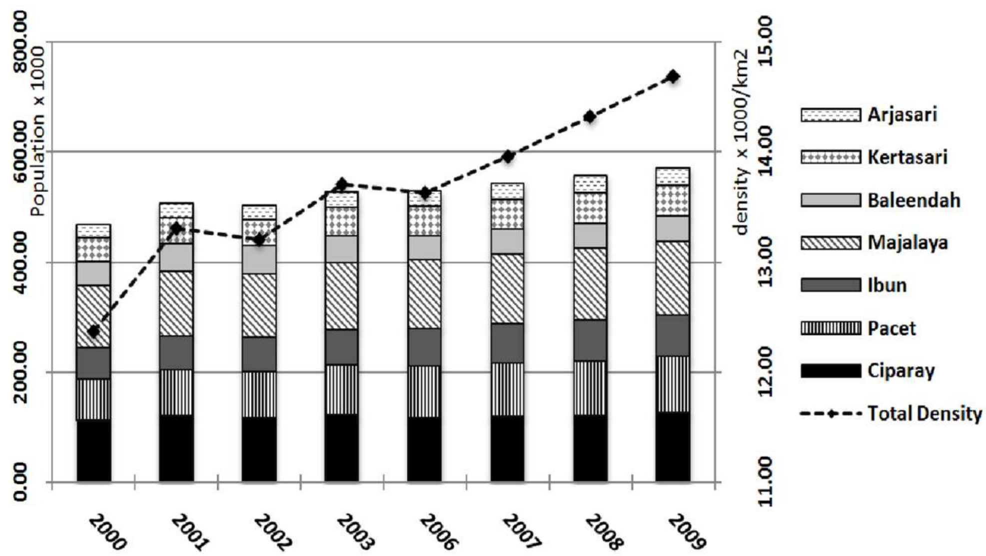


Figure 5.6. Population growth of 7 sub regencies and total density 2000-2010

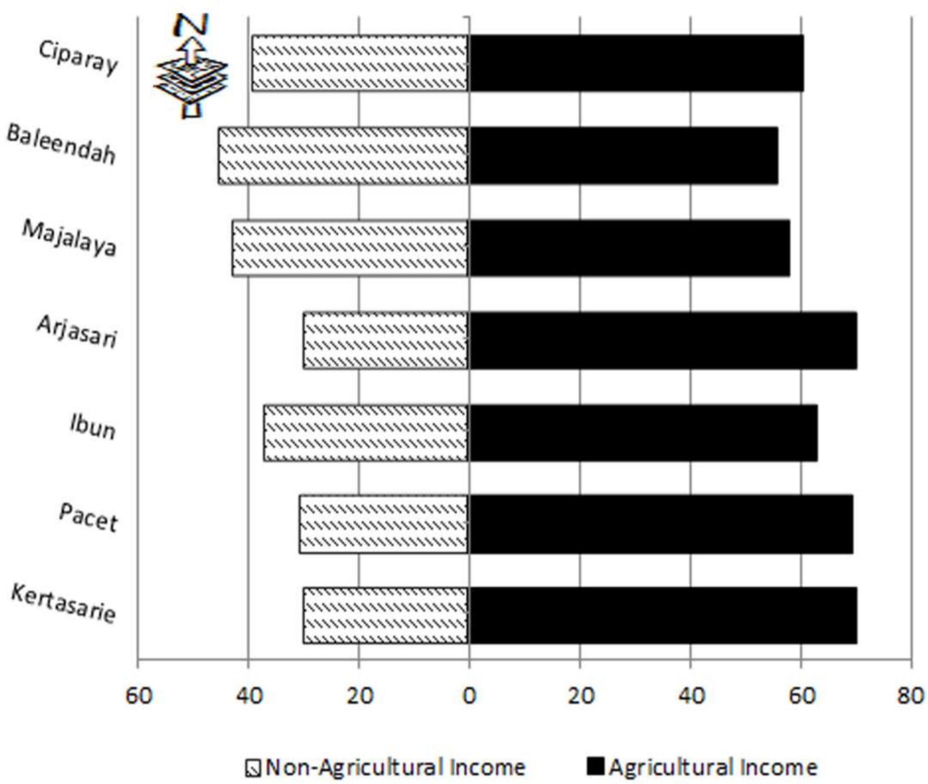


Figure 5.7. Income contribution of two main sectors in Cirasea sub-watershed

Moreover, in Figure 5.7, the comparison of the distribution of priority determination change on land degradation depicted that the majority of degradated lands belong to the priority 1 and priority 2 for about 71.36% in 2003 to 73.36% in 2010. Therefore, it can be said that the present rate of land degradation is denoted as high priority level, and there is a probability that the rate of land degradation will increase in the future.

However, this is only a cumulative effect of changes for the entire sub-watershed that may not facilitate the full picture of spatial changes in land degradation at the practical management unit and their priorities so that future soil conservation and reforestation efforts can be implemented. Therefore, comparison of priority determination on handling land degradation was carried out a sub-watershed level to provide the watershed manager better information on the change on spatial extent and intensity of land degradation. Sub-watershed was placed in a priority list in descending order of their potential soil erosion, population pressure and land degradation.

5.5 Conclusion

By integrating biophysics and socioeconomic aspects, this study revealed insights into the important change of LULC change, soil erosion, population pressure and priority determination on handling land degradation. Moreover, the results of the study that integrating biophysics and human pressure can provide useful ideas and insights to land use planners and managers especially for conservation (Rogers et al., 2010).

The results of this study stated the existence of LULC change in Cirasea sub-watershed for the last seven years. In particular, the expansion of paddy field, plantation and settlement decreased forest and grassland area. The LULC change analysis disclosed the change in LULC in the form of conversion. Consequently, due to the ever increasing population and the increasing demand for resource create great pressure on the natural resources and as a result, degradation of vegetation cover existed and potential soil erosion. A wider LULC change associated with the broader range of impact on the terrestrial resources such as soil and land degradation where soil degradation is the problem associated with LULC change that can be found in the study area. Agriculture activity such as paddy field and plantation played a decisive role in the LULC change and then land degradation over the area. Besides agriculture, the unwise use of forest, grassland and settlement can be worsening for the soil and land degradation over the area.

To conclude, the importance of LULC dynamics and priority determination policies in response to LULC change has been recognized. It can be concluded that the LULC change and population pressure cannot be ignored for priority determination on handling land degradation.

Chapter 6

Sustainability assessment in humid tropical watersheds: a case of Batang Merao Watershed, Indonesia

6.1 Introduction

Degradation of forest, land and water resources and population pressure have brought long-term reduction of watershed sustainability that can be the greatest constraints to sustainable watershed management in most developing countries in humid tropics (Wohl et al., 2012). Humid tropical Asia presents the highest deforestation and forest degradation among other regions (Latin America and Africa) that are the effect of high population pressure. This sustainability issue is specifically a big challenge in Indonesia due to two facts as follows:

1. Indonesia has been experiencing intensive land use change in the last three decades (Wicke et al., 2008);
2. Deforestation, land and water degradation in most of the Indonesian watersheds are in critical point and declining quality under pressure (Murdiyarso et al., 2002; Wicke et al., 2008).

The vital importance of biodiversity, water, energy, and food security in sustaining human and environmental services has been recognized in numerous national and international fora e.g. the UN-Earth Summit 1992 in Rio, the UN-world summit on sustainable development 2002 in Johannesburg, Sustain Conference 2010-

2012 in Kyoto, River symposium 1-16, World Energy Congress, etc. The importance of watershed sustainability has become more relevant because of the increasing awareness that the sustainability of watershed functions is an essential requisite for sustainable future and human security. As serious global issues, both food security and environmental issues are related to and need to be addressed within the context of watershed management (Wicke et al., 2008).

Because sustainable watershed management is a central challenge in the context of sustainable development (Swami and Kulkarmi, 2011), its management has to ensure food and human security and protect environment from negative consequences such as ecosystem degradation, pollution, and climate change. Unfortunately, for most countries especially in humid tropical region, watershed management is still viewed from the narrow perspective of benefits to water projects alone while it should be in holistic perspective and should be considered essential for soil and water conservation, which in the long run will enhance the prospect of self-reliance of nations in terms of food and energy (Biswas, 1990). In addressing the sustainable future relating to food and water security, this research highlights issues that require integrated indicators in assessing the level of security or sustainability associated with watershed management.

Due to the fact that assessment for watershed sustainability in Indonesia, especially in Sumatera Island, is still in its infancy, this study aimed to assess the sustainability of Batang Merao Watershed for the period of 2006-2011 using HELP indicators.

6.2 Material and methods

6.2.1 Study area

The landscape selected for this research was the watershed of Batang Merao, which covers approximately 67,874.48 ha and is an upstream of the Batang Hari river basin. Located in northwest of Jambi Province, Indonesia, it lies between 01°42’19” - 02°08’14” South, 101°13’11”- 101°32’20” East. The elevation ranges from 767 to 3,266 m above sea level (see Figure 3.1, chapter 3 pp 64). It is situated in a humid tropical zone with 2,495 mm yr^{-1} of its annual mean precipitation over the last 20 years, meanwhile the annual mean temperature over the last 10 years was 23.1^0C.

The Batang Merao watershed, which lies within 10 sub regencies and 124 villages, plays an important role in serving regional economic development of Kerinci Regency and Jambi Province. Most of the agricultural lands in these regions depend on this watershed for water supply. As it is a buffer zone of a UNESCO tropical rainforest heritage site in Kerinci Seblat National Park, maintenance of the protected area around the watershed is also an essential requirement for regional development. The issues of regional economic development and environmental degradation in the watershed are of great concern to the government. However, there is a clear general lack of sustainability information of this tropical watershed, making it essential to carry out more comprehensive sustainability studies. A comprehensive research is necessary to look at the integrated indicators of watershed management for ecosystem degradation, socio-economic problems and policy.

6.2.2 Data

The primary data for Hydrological indicator were collected by primary field survey on September 20, 2011 while the secondary data were obtained from the Environmental Management Agency of Jambi Province. Water samples were collected from 15 stations of selected catchments within Batang Merao Watershed (see Figure 2.4 chapter 2 pp 48). Most of these stations were located in the upper-middle-downstream area of Batang Merao Watershed. For the Environment indicator especially land cover data, Landsat image ETM data (path 126/row 61; year of 2006 and 2011) were used in this study. For supporting image analysis, some ancillary data were used including ground truth data (83 samplings) acquired through the field survey (September 10-15, 2011; see Figure 2.5 chapter 2 pp 52). Regarding the Life indicator, the HDI component (expenditure, health and education) as a secondary data were obtained from regional development planning (Jambi Province and Kerinci Regency) from 2006 to 2011. Finally, the Policy indicator data were retrieved from Center for Batanghari Watershed Management, Forestry Office of Jambi Province.

6.2.3 Analysis

The Hydrology indicator contains two sets of sub-indicators: water quantity and water quality. In order to analyze water quality, the collected data of physical, chemical, and biological parameters (Temp, TDS, TSS, pH, BOD, COD, DO, P, NO_3 and Coliform) were analyzed by using the Water Pollution Index (WPI) and STORET method. The laboratory analyses of those parameters were determined according to the national standard of water quality status in Indonesia (Ministry of Environment of Indonesia, 2003).

Table 6.1. A summary of HELP indicators and parameters of watershed sustainability index

Indicators		Parameters		
		Pressure	State	Response
H (Hydrology)	Quantity (Δ1)	variation per capita water availability ($m^3 \cdot person^{-1}.year^{-1}$)	water availability per capita ($m^3 \cdot person^{-1}.year^{-1}$)	water-use efficiency
	Quality (Δ2)	variation BOD_5	average long term BOD_5	sewage/disposal treatment
E (Environment)		environmental pressure index (forest and population)	percent of area under vegetation/forest	evolution conservation areas
L (Life)		variation HDI expenditure	Human Development Index	evolution in the HDI
P (Policy)		variation HDI-Education	institutional/management	expenditure for watershed

Adopted from IHE-UNESCO (2001); Chaves and Alipaz, (2006); and Cortés *et al* (2012)

The Environmental indicator was determined by Environmental Pressure Index (EPI) which was derived from land change data. In order to analyze land change, several technical methods such as supervised classification, an accuracy assessment, and the Kappa coefficient method were implemented. LULC classification was modified from the LULC categories of the Indonesian National Standard no. 7645:2010 specified by the National Standard Agency of Indonesia which refers to the FAO's land cover classification system and ISO 19144-1 (BSN - National Standarization Agency of Indonesia, 2010). The Life indicator is related to the HDI, which gives information on the evolution of the minimum life quality in the watershed. The Policy indicator evaluates the levels of HDI-education, institutional performance/legality, and integrated budgeting for watershed management.

Although there are many environmental and water indices, they are not basin-specific, and do not aim to access basin sustainability with respect to integrated water resources management (Chaves & Alipaz, 2006). In this study, the HELP, a UNESCO integrated watershed sustainability index, was employed to assess the sustainability level of the watershed. The reason why this applied HELP was set up for this research is that Watershed Sustainability Index (WSI) is an integrated indicator based on basin Hydrology, Environment, Life and Policy conditions which include describing and assessing relevant socio-economic data (IHE-UNESCO, 2001). HELP is creating a new approach to integrated watershed management through the creation of a framework for watershed management under three indicators: pressure, state and response (PSR) approach. The structure of PSR approach incorporates cause-effect relationships and thus provides a more comprehensive understanding of the watershed than an index which only examines the state. The HELP indicators was established by UNESCO since 1999 and have been applied in more than 91 river basins in 67 countries such as the Murrumbidgee catchment in Australia (Khan, 2004), Verdadeiro river basin in Brazil (Chaves and Alipaz, 2006), the Elqui river basin in Chile (Cortés et al., 2012) and Langat river basin, Malaysia (Elfithri, 2013).

Each indicator in Equation 2.4 (see chapter 2 pp 58) is derived from the integrated analysis mentioned in Table 6.1 which considers important factors such as PSR approach. The approach is often used in environmental reports as it provides a useful and simple tool to formalize environmental problems (Levrel et al., 2009). In addition, this approach lies in the fact that it takes into account cause-effect relationships, allowing different stakeholders, managers, and decision makers to recognize and understand the interconnections between the indicators (OECD, 2003).

Table 6.2. Description of the WSI pressure indicators, level and scores

Indicators	Pressure parameters	Level	Score
Hydrology	Δ1- variation in the watershed per capita water availability in the period studied, relative to the long –term average (m^3.person-$^{1.}$ year^{-1})	Δ1 < -20%	0.00
		-20% < Δ1 < -10%	0.25
		-10% < Δ1 < 0%	0.50
		0% < Δ1 < +10%	0.75
		Δ1 > +10%	1.00
	Δ2-variation in the watershed BOD_5 in the period studied, relative to the long-term average	Δ2 > +20%	0.00
		+10% < Δ2 < +20%	0.25
		0% < Δ2 < +10%	0.50
		-10% < Δ2 < 0%	0.75
		Δ2 < -10%	1.00
Environment	Environmental pressure index (EPI) in the period studied	EPI > +20%	0.00
		+10% < EPI <+ 20%	0.25
		+5% < EPI < +10%	0.50
		+0% < EPI < +5%	0.75
		EPI < 0%	1.00
Life	Variation in the watershed per capita Human Development Index (HDI)-Income* in the period studied, relative to the previous period	Δ < -20%	0.00
		-20% < Δ < -10%	0.25
	(*:this study used HDI-expenditure data instead of HDI income data)	-10% < Δ < 0%	0.50
		0% < Δ < +10%	0.75
		Δ1 > +10%	1.00
Policy	Variation in the watershed HDI-Education in the period studied, relative to the previous period	Δ < -20%	0.00
		-20% < Δ < -10%	0.25
		-10% < Δ < 0%	0.50
		0% < Δ < +10%	0.75
		Δ > +10%	1.00

Adopted from IHE-UNESCO (2001); Chaves and Alipaz, (2006); and Cortés *et al* (2012)

The WSI indicators and parameters, including their levels and scores, are presented in Tables 6.2, 6.3, and 6.4. The WSI was computed as all indicators have a certain range of value index (0 – 1). As the result, the watershed sustainability can be computed in the equation 2.4 (see chapter 2 pp 58).

Table 6.3. Description of the WSI state indicators, level and scores

Indicators	State parameters	Level	Score
Hydrology	Watershed per capita water availability (m^3.person-1. $year^{-1}$), considering both surface and groundwater sources	Wa < +1700	0.00
		+1700 < Wa <+ 3400	0.25
		+3400 < Wa < +5100	0.50
		+5100 < Wa < +6800	0.75
		Wa > +6800	1.00
	Watershed averaged long term BOD_5 (mg.L^{-1})	BOD_5 > +10	0.00
		+10 < BOD_5 < +5	0.25
		+5 < BOD_5 < +3	0.50
		+3 < BOD_5 < +1	0.75
		BOD_5 < +1	1.00
Environment	Percent of watershed area under natural vegetation (Av)	Av < +5	0.00
		+5 < Av < +10	0.25
		+10 < Av < +25	0.50
		+25 < Av < +40	0.75
		Av > +40	1.00
Life	Watershed Human Development Index (HDI), weighed by county population	HDI < +0.50	0.00
		+0.50 < HDI < +0.60	0.25
		+0.60 < HDI <+0.75	0.50
		+0.75 < HDI < +0.90	0.75
		HDI > 0.90	1.00
Policy	Watershed institutional capacity in Integrated Water Resources Management (legal and organizational)	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00

Adopted from IHE-UNESCO (2001); Chaves and Alipaz, (2006); and Cortés *et al* (2012)

Table 6.4. Description of the WSI response indicators, level and scores

Indicators	Response parameters	Level	Score
Hydrology	Improvement in water-use efficiency in the watershed	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00
	Improvement in adequate sewage treatment/disposal in the watershed, in the period studied	Very poor	0.00
		Poor	0.25
		Medium	0.50
		Good	0.75
		Excellent	1.00
Environment	Evolution in watershed conservation areas (Protected areas and Best Management Practices), in the period studied	$\Delta < -10\%$	0.00
		$-10\% < \Delta < 0\%$	0.25
		$0\% < \Delta < +10\%$	0.50
		$+10\% < \Delta < +20\%$	0.75
		$\Delta > +20\%$	1.00
Life	Evolution in the Human Development Index in the watershed, in the period studied	$\Delta < -10\%$	0.00
		$-10\% < \Delta < 0\%$	0.25
		$0\% < \Delta < +10\%$	0.50
		$+10\% < \Delta < +20\%$	0.75
		$\Delta > +20\%$	1.00
Policy	Evolution in the Water Resources Management expenditures in the watershed, in the period studied	$\Delta < -10\%$	0.00
		$-10\% < \Delta < 0\%$	0.25
		$0\% < \Delta < +10\%$	0.50
		$+10\% < \Delta < +20\%$	0.75
		$\Delta > +20\%$	1.00

Adopted from IHE-UNESCO (2001); Chaves and Alipaz, (2006); and Cortés *et al* (2012)

6.3 Results

The research findings can be divided into four broad indicators and one overall assessment as results of HELP indicators and the overall watershed sustainability index in the last section as follows:

6.3.1 Hydrology Indicator

The calculated values for Hydrology quantity and quality were summarized in Table 6.5. In the case of the water quantity, Batang Merao watershed has a long term (1985-2011) average flow of 190.70 $m^3 s^{-1}$ and a short term (2006-2011) average of 202.78 $m^3 s^{-1}$. Divided by a total watershed population of 229,009 inhabitants (in 2011), the per capita water availability (Wa) is 3,481.24 m^3 $person^{-1}$ $year^{-1}$. The score for the state quantity parameter is 0.50. The variation in Wa, with respect to the long-term average, was +0.90% with the pressure quantity score of 0.75. In the case of quantity response, the only regular activities for improving water use efficiency were maintenance of physical infrastructures, farm facilities, and small micro-hydro facilities, which resulted a score of 0.5.

Table 6.5 Calculated values for Hydrology indicator

	Pressure		State		Response		WSI
	Value	Score	Value	Score	Value	Score	Score
Hydro Quantity	0.90	0.75	3,481.24	0.50	medium	0.50	0.58
Hydro Quality	8.95	0.50	4.44	0.50	medium	0.50	0.50
Average		0.63		0.50		0.50	**0.54**

As the result, the average score for Hydrology quantity in the watershed was (0.75+0.50+0.50)/3=0.58. Because of the lack of time series information on water quality, the long term and short term analysis were obtained from the secondary data (for the year of 1990, and from 2006 to 2010), and the primary data (for the year of 2011). In the case of the water quality parameters, pressure related to the variation in the watershed BOD_5 (+8.95%) with a score of 0.75. For the state parameter, the value of 4.44 $mg.l^{-1}$ contributed a score of 0.50. The response parameter resulted in a score of 0.50 (medium improvement in sewage treatment/disposal). The Hydrology quality indicator was therefore (0.50+0.50+0.50)/3=0.50. Hence, the overall Hydrology indicator value was 0.54.

Table 6.6. Calculated values for Environment indicator

Pressure		State		Response		WSI
Value	Score	Value	Score	Value	Score	Score
-23.01	1.00	18.13	0.50	7.14	0.50	**0.67**

6.3.2 Environment Indicator

Table 6.6 summarizes the results for this indicator. In the case of pressure, the combined watershed variation in forest area and population in the period studied were -25.09% and 20.93%, respectively, resulting an EPI value of -23.01%. This finding corresponds to an environmental pressure score of 1.00. In the case of environmental state, the watershed maintained 18.13% of its original vegetation coverage in the year 2011, resulting in a score of 0.50. Regarding environmental response, there was an increasing forest rehabilitation from 980 ha (2006) to 1,050 ha (2011) respectively, resulting a score of 0.75. Therefore, the overall score for the Environment indicator was 0.67.

6.3.3 Life Indicator

The summary of Life indicator was shown in Table 6.7. By calculating the variation in the watershed's HDI-Expenditure in the study period, life pressure in the watershed, a score of 0.75 was obtained. In the case of life state parameter, the watershed HDI was 0.73, resulting in a score of 0.50. The life response, i.e., the evolution of the expenditures in the watershed, was +2.01%, resulting in a score of 0.50. As the result, the overall Life score for the watershed was 0.58.

Table 6.7. Calculated values for Life indicator

Pressure		State		Response		WSI
Value	Score	Value	Score	Value	Score	Score
2.45	0.75	0.73	0.50	2.01	0.50	**0.58**

Table 6.8 Calculated values for Policy indicator

Pressure		State		Response		WSI
Value	Score	Value	Score	Value	Score	Score
0.04	0.75	medium	0.50	7.05	0.50	**0.58**

6.3.4 Policy Indicator

The scores for Policy indicator were summarized in Table 6.8. The score of policy pressure (variation in the HDI-Education sub-indicator) for the watershed was +1.08%, resulting in a parameter score of 0.50. The policy state score was based on watershed institutional capacity and performance with a score of 0.50. With regard to policy response, the evolution in the watershed expenditures was +7.05%, resulting a value of 0.50, as shown in Figure 6.1. Therefore, the overall score for Policy indicator was 0.58.

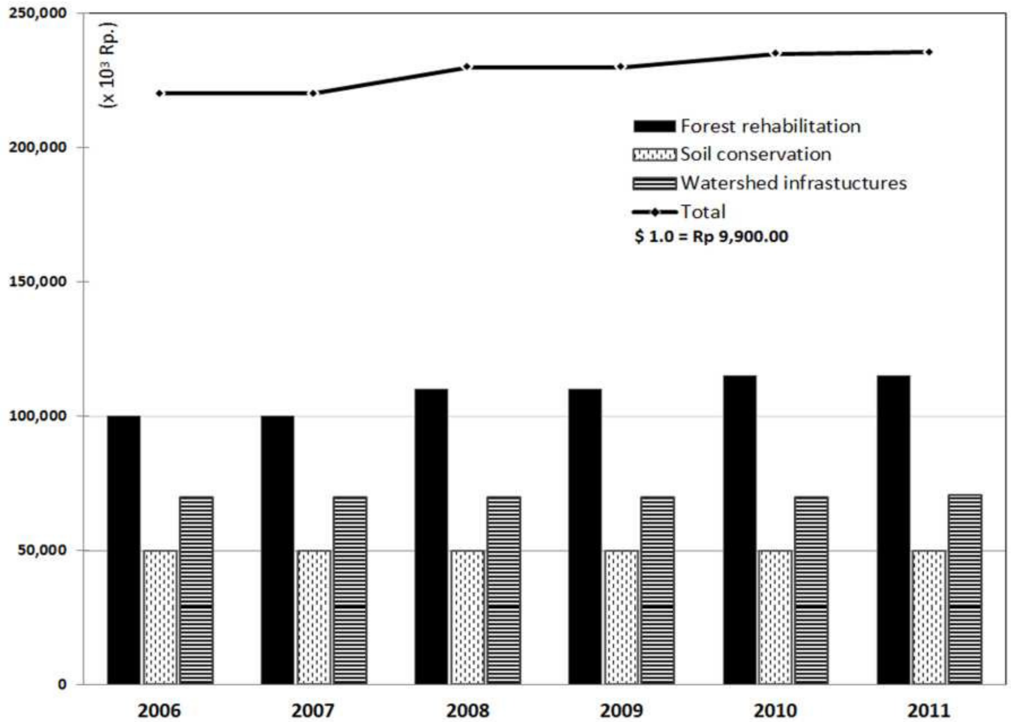


Figure 6.1. Evolution of watershed management expenditure from 2006-2011

Table 6.9. An assessment summary of the watershed sustainability index

	Pressure	State	Response	Result
Hydrology 1	0.75	0.50	0.50	
Hydrology 2	0.50	0.50	0.50	
Hydrology (average)	0.63	0.50	0.50	0.54
Environment	1.00	0.50	0.50	0.67
Life	0.75	0.50	0.50	0.58
Policy	0.75	0.50	0.50	0.58
Result	0.78	0.50	0.50	**0.59**

6.3.5 Overall WSI Assessment

The value index for watershed sustainability was summarized in Table 6.9. The overall WSI index of the Watershed was 0.59 which was classified into intermediate level of watershed sustainability. Simultaneously, the lowest score of indicators was Hydrology (0.54), whereas the highest was Environment (0.67). Concerning the PSR parameters, the highest score was pressure (0.78), and the lowest were both state and response (0.50). It indicated that the watershed was still in high pressure and exceeded the management capacity in maintaining the watershed sustainability.

6.4 Discussion

This study successfully integrated HELP indicators for assessing the sustainability level of Batang Merao watershed. With the overall WSI score of 0.59, the watershed was an intermediate level of watershed sustainability. In comparison to the other watersheds in the humid tropical countries, Batang Merao watershed was at the lower level than others with respect to the WSI value in Verdadeiro ariver basin, Brazil (0.65) (Chaves and Alipaz, 2006), the Reventazon River, Costa Rica (0.74) (Catano et al., 2009) and Langat river basin, Malaysia (0.65) (Elfithri, 2013). This means that this watershed needs kinds of improvement or management to achieve the better level of watershed sustainability (>0.59).

The environmental pressure was still higher than the management's response to solve the pressure (Figure 6.2). This condition could be due to the land use land cover change. It was noted that the deforestation rate was 824.14 ha yr^{-1} in other sides, several areas had increased such as agricultural land, mix plantation and settlement, as described in Figure 6.3. This improper land use change is a major barrier for watershed sustainability (Wang and Innes, 2005) and could become a serious problem in the future. Therefore, in land use management, the result emphasized the need of protection and conservation for the forest area in much of the areas in rapidly dynamic change of the watershed. In addition, integrated watershed management programs, such as soil and water conservation as well as the wise use of land and water, need to be effectively improved.

The study also revealed that the pressure parameters of hydrological, Life, and Policy indicators were higher than the state and response parameters. To overcome HELP indicators leading to pressure parameters especially for environmental degradation, the demands for sustainable watershed management need to be transposed into policy and practical regulation and action that allow a harmonic development in the watershed with the wise use of land and natural resource and the effective performance of watershed management. Appropriate policy response, therefore, require a better understanding of HELP indicators values and progresses, ranging from national policy, local regulation and collective community and partnership decisions. In order to support watershed sustainability, attention should be paid to integrated watershed programs about landscape change, eco-hydrological effects and strong supports from institutional arrangements and partnership in watershed management.

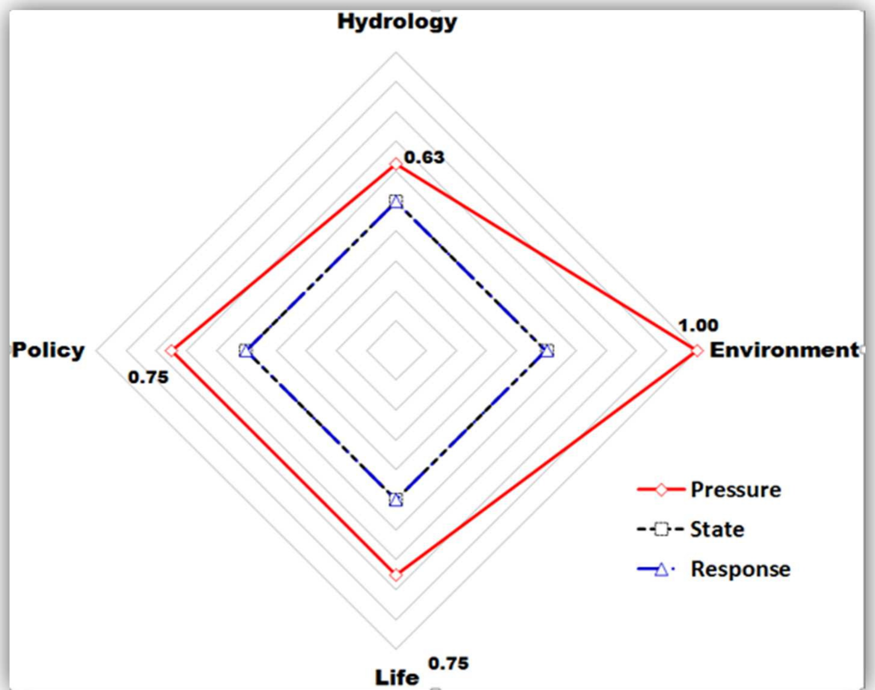


Figure 6.2. Pattern of applied HELP indicators in Batang Merao Watershed

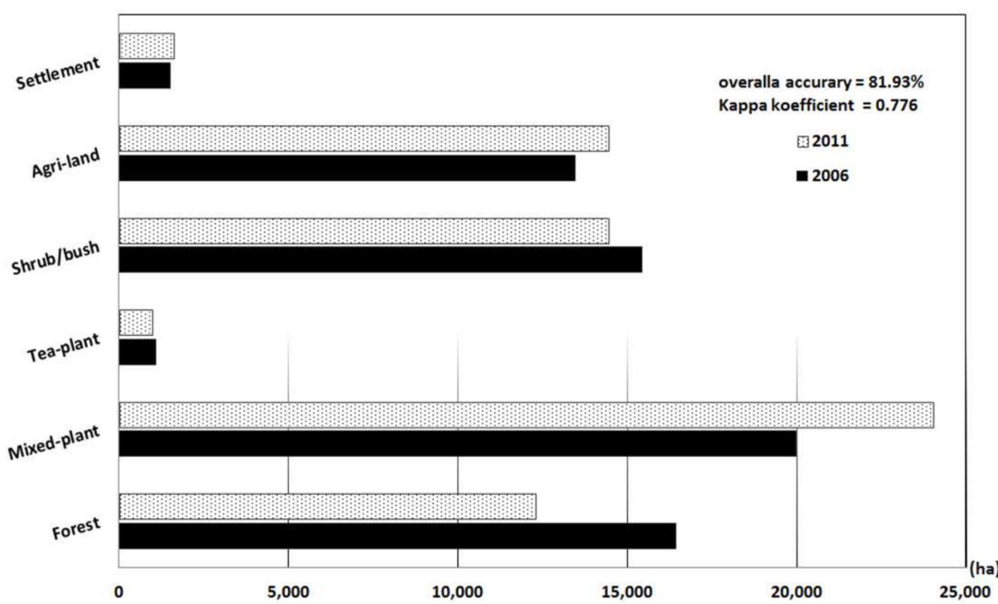


Figure 6.3. Distribution of LULC change in Batang Merao watershed 2006- 2011

6.5 Conclusion

The results showed that the watershed was at an intermediate level of watershed sustainability and was still in high pressure due to its pressure parameter score which was higher than the state and the response parameters. Therefore, it is urgent to improve the integrated watershed management programs for achieving the better sustainability of this watershed.

Improving watershed sustainability will require some combinations of regulation such as better land use planning, education, and economic incentives (Wagner et al., 2002), improvement in criteria and indicators for temporal and spatial assessment (Wang and Innes, 2005), conservation programs, and improve institutional capability and broad community participation. For humid tropical watershed like Batang Merao Watershed, the sustainability could be achieved by improving sustainability guidelines of HELP indicators.

Chapter 7

General discussion and conclusion

At first glance, it seems difficult to draw conclusions based on the six preceding chapters. Assessment of LULC change toward watershed sustainabilty requires a profound knowledge of pattern, process, driving force and ecological impacts of LULC change. As a consequence, watershed sustainability cannot be overviewed well without understanding of the properties of LULC change and watershed dynamics. It is therefore very important to assess LULC change incorporate with sustainability in humid tropical watersheds in Indonesia. Information on LULC change (driving forces and ecological impacts) and watershed sustainability will help relevant program that can be designed to improve the quality of land management and watershed sustainability. So far, this research produced the first assessment of LULC change incoorporate with sustainability assessment of humid tropical watershed in Indonesia especially in the study area of Batang Merao watershed.

This chapter discusses the major scientific findings and implications, recognizes the limitation of the study and future perspective of the study, and finally concludes overall research findings and suggests important recommendations and a continuing research proposal.

7.1 Major scientific findings and implications

7.1.1 Patterns and socio-economic determinants of LULC change

LULC change patterns in Batang Merao Watershed have been primarily produced by some socioeconomic driving forces. Population growth has led to increasing pressure on land as consequence of the growing need of agricultural demands. This study revealed that dynamic of LULC showed an increase in agricultural area (mix plantation and agricultural land), with mainly at the expense of forest and shrub/bush land. On the contrary, forest land decreased dramatically. The proximate socioeconomic driving factors that significantly involved in the dynamic of LULC change were population growth/pressure, number of farmers, GDRP agriculture, GDRP total, and HDI. Change in LULC and its dynamics were closely associated with human activities in the region such as the expansion of agricultural area (mix plantation and paddy field). In a similar study, Liu *et al* (2008) revealed that population and GDP (agriculture and industry) have a significant effect on the landscape dynamics due to LULC change.

The findings of this research agree that the consequent high pressure on resources are expected to have an adverse effect on the existing natural resources of the area through increasing the demand for food and other necessities. Growing population pressure and its associated problems, such as the increasing demand for land and agricultural products, limited land-hold shares, and the lack of non-agricultural income, have been the major socio-economic driving forces of LULC change.

Agriculture was and is the dominant change in the study area, as most of the population heavily relies on this sector for food and main economy activity. Even though the drivers of the LULC are complex in nature, the study further affirms and shows that socioeconomic driving forces play an important role in influencing land change, especially in the agricultural sector as this is the main economy humid tropical watershed in Indonesia. This study is in line with a similar study in landscape dynamics, Pena *et al* (2007) concluded that land-use changes are correlated with socioeconomic structural forces.

The above major findings in determining patterns and determinants of LULC change make some important implications for land and watershed management in Indonesia. This is critically important for sustainable watershed management where agriculture is the major income for most people in and around the watersheds. Understanding the pattern, process and socioeconomic implications of LULC change will help in better decision making with sound and sustainable outcomes. Furthermore, additional factors influencing land cover changes are related in a complex manner and this study provides a better understanding of the process.

To overcome this condition, several important efforts should be taken as follows:

1. Attention should be given to the introduction of wise land resource uses and management practices and secure land tenure systems.
2. In this regard to sustainable land management, conservation strategies for natural, agricultural, and pro-environment local economic activities, should be a priority for land managers and relevant stakeholders.

3. From the standpoint of local economic policy, local people in and around watershed should be helped to increase their non-agricultural income. With the quarantee of this alternative economic opportunities, they could possible protect forest and maintain the watershed.
4. Thereby, adopting an integrated ecosystem management at the watershed scale is of special importance (Chettri et al., 2013) through the following activities such as adjustment of the land use pattern, diversification of agricultural income and low risk on agricultural production

7.1.2 Ecological impacts of LULC change

The assessment of LULC in humid tropical watersheds reveals that the LULC change have adversely affected the watersheds in Indonesia. The watersheds have suffered serious ecological impacts during study period as a result of changes in LULC especially deforested areas and agricultural increase. The consequences of these problems include reduction in protected area, degradation of water quality and increase in land degradation.

Concerning land degradation, Batang Merao Watershed exhibited potential soil degradation where the mean annual potential land degradation increased from 128.03 ton ha^{-1} y^{-1} in 1990, 144.68 ton ha^{-1} y^{-1} in 2000 and 194.14 ton ha^{-1} y^{-1} in 2010. Among the USLE factors, the value of the LULC factor was dynamic over time and increased the total value and level of potential land degradation. This study reveals that there is relationship between LULC change and land degradation that land cover type plays an important role in protecting soil from land degradation in this watershed.

Since land degradation and soil erosion are amongst key factors determining the ecological sustainability (Shi et al., 2004) and as important agricultural problem, the effects of land degradation must be adequately addressed. As implication, therefore, in order to prevent the areas from an extremely high level of land degradation, the proper use of land cover and soil conservation program are highly recommended to be widely implemented in the tea plantation and agricultural land. Implementation of best agricultural practices, tillage operation, and development of vegetative cover in wasteland would be suggested for reducing land degradation (Sharma et al., 2011). For this reason, multipurpose agro-forestry should be introduced that can satisfy the need for wood, livestock fodder, soil fertility improvement, and soil and water conservation (Mengistu, 2008). Furthermore, Chen *et al* (2013) stated that diversification of agricultural income and low risk on agricultural production is required for sustainable land development.

Regarding the water quality, it can be concluded that water quality degradation in the watershed was associated with LULC types which were generally good predicators of water quality conditions. The given water quality status by government was inappropriate due to some changes in downstream and midstream area. Batang Merao watershed was classified as lightly polluted (86.67%) and moderately polluted (13.33%) meanwhile, the STORET results indicated that about 80% of them were moderately polluted. As implication that there is a growing need to evaluate the status of water quality in order to anticipate its potential negative impacts of water quality degradation in the watershed.

The intesive land change to agricultural land is then considered potential threats for watershed sustainability. In addition, non-point pollution caused improper use and overuse of chemical fertilizer and pesticides has been found in most agricultural area especially in the upstream area. Proper land use and water management is needed for sustainable functions of economic and conservation aspects in the watershed. Since this study can help us better understand LULC status, water quality, and their relationship, LULC should be well managed and some conservation programs should be taken in order to minimize the potential impact on water quality. This findings revealed that the study could provide critical information on sustainable land use practice for water resource conservation for the tropical watershed.

7.1.3 LULC change in West Java, a comparative study

A comparative study in Cirasea sub-watershed found that most areas of Cirasea sub-watershed were high soil erosion, more population pressure and degradated land areas that are more complex than watershed problems in Batang Merao watershed.

The alarming increase of Cirasea's population density is the cause of the persistent land change problems. It is a challenge to deal with the increase of agriculural lands as a big pressure on land use. It is challenging to find solutions for socio-economic issues since it is very hard to stop population increase. Hence, Java island, such as Cirasea sub-watershed must cope with this threat on a different way. One of the most reliable idea is that applying agroforestry system in land use practices.

Because of the high population growth, it should be better to involve people participation in the soil conservation and reforestation program. Forest rehabilitation and soil conservation should be carried out with full participation of the beneficiaries to restore the degraded areas base on priority determination. Rahman *et a*l (2009) suggest that the priority should be given to control the rate of soil degradation by conservation planning. Also, Rescia *et al* (2010) suggest that conservation management of land degradation should be adaptive and involve the participation of local population. Learning from Japanese cultural landscape, a plan system should be proposed together with guidance for conservation, management, utilization and participation multistakeholders (Ohta and Nakagoshi, 2011).

7.1.4 Sustainability in humid tropical watersheds in Indonesia

Sustainability assessment of watershed can be described as sustainability of watershed management in completely important aspects namely hydrological response, environmental performance, life indicator, and policy making. The HELP indicators have advantages in integrity (Chaves and Alipaz, 2006), simplicity, flexibility, and adaptability (Cortés et al., 2012).

As a goal, this study concluded that Batang Merao watershed was at an intermediate level of sustainability and was still in high pressure due to its pressure parameter score which was higher than the state and the response parameters. The achievement of watershed sustainability is not as simple as technical issues. It has become part of a complex interaction of ecology, socio-economic and policy process. It also need to be ensuring a long-term watershed management program while at the same time minimizing ecosystem degradation and maintaining the multi-functions of hydrology, environment, life, and policy indicators.

Like the functions of other environmental indeces, HELP indicators have opportunity to distinguish the degree of watershed sustainability. As consequences, it is urgent to improve the integrated watershed management programs for achieving the sustainability of this watershed. Improving watershed sustainability will require some combinations of regulation such as better land use planning, education, and economic incentives (Wagner et al., 2002), improvement in criteria and indicators for temporal and spatial assessment (Wang and Innes, 2005), conservation programs, and improve institutional capability and broad community participation.

The obtained WSI can play a number of useful roles in the policy process (de Sherbinin et al., 2013; OECD, 2008). For example there are the potential helps of watershed management in describing issues by reducing complexity, diagnosing problems through the analysis of trends or correlations with other indicators or watersheds, helping analysts to discover patterns within and across units of analysis, identifying best and worst practices, helping society to deliberate about desired futures and possible solutions to environmental concerns, and holding policy makers and program managers accounTable. WSI has a goal to measure sustainability, which can be used to assist decision makers and other stakeholders in achieving sustainability. Further, WSI can also be used to communicate the progress of sustainability to wider community. For example, the application of WSI in Batang Merao Watershed for differents years can be used to show the community how the watershed has progressed toward watershed sustainability.

This WSI research is the first study conducted in humid tropical watersheds in Indonesia as well as in Batang Merao watershed incoorporate with UNESCO-HELP indicators. It will be emerging and potentially research ideas that can be followed and implemented widely by other watersheds in Indonesia.

7.2 Limitations of the study

The present research is not completely free of limitation and it needs much more developing ideas and supports as follows:

1. Insufficient some important data including socioeconomic data, historical LULC data, and regularly fine satellite Image negatively affected the accuracy and detail analysis. It is important to note that the data availability of long-term socioeconomic, historical, and physical LULC data would have given a clear pattern of LULC pattern and trends in relation to the changing environmental and anthropogenic influences. These data should be integrated completely in the future studies.
2. As the broad impacts of LULC change will affect not only ecological impacts but also socio-economic aspects of human life, a complete ecological and economic assessment which is very important for the study of LULC dynamics was out of the realm of this study.
3. No specific and advanced LULC model introduced or developed in the study: It is generally agreed that the gaps in knowledge become obvious during the model-building process and the sensitivity of LULC. It should be believed that modeling is one of the methods in the portfolio of techniques and approaches available to unravel the dynamics of the land-use system. The need and

importance of modeling involve the use of artificial representations of the interactions within the land-use system to explore its dynamics and possible future development.

7.3 Future perspectives of the research

At the end of this study, the list of new issues to be investigated is often longer than the list of research findings. Due to the limitation of the study, there is the need for further studies, and the following suggestions are relevan for future research.

1. Developing models and scenario is amongst the needed step in the emergce land change science. For example, there are 4 new conceptual models in linking land change with driving forces and actors namely model driving force-land change (DF-C), model driving force-actor-land-change (DF-A-C), model driving force/actor-land change (DFA-C), and model actor-land change (A-C) (Hersperger et al., 2010).
2. More advanced GIS application and finer resolution remote sensing data should be integrated in future studies.
3. For estimating potensial erosion, it is strongly recommended to simulate the erosion parameter with the new prediction model instead of USLE' mathematical model. The following models can be used to estimate erosion such as RUSLE, WEPP, SWAT, WATEM, ANSWERS, KINEROS, AGNPS, LISEM, STREAM, RillGrow models, etc.
4. For the water quality, only 9 of 32 water quality parameters were simulated in this dissertation. The rest parameters should be further analyzed and correlated to LULC data for advanced research on this concern.

5. Regarding the broad impact of LULC change, it is believed an inventory of environmental economic evaluation and assessment of ecosystem services would permit a better generalization of the underlying cause for ecosystem changes for future studies.
6. Regarding HELP indicators, there is open room for development of this method as its approaches are still based on the old concept of PSR framework. In line with this context, tt is also important to provide proposal and guidance for assessing humid tropical watershed in Indonesia, e.g. designing rapid asseessment for watershed sustainability.

7.4 Conclusions, recommendations and proposal

7.4.1 Conclusions

This study addresses important subjects on the study of LULC change that are of great practical relevance and have the potential applications for the management of humid tropical watersheds in Indonesia. The main contribution of this study is that it was successful in assessing LULC change and its ecological impacts, and could contribute to land and watershed planning in order to achieve sustainability in humid tropical watersheds in Indonesia. In conclusions, this study makes the following contributions:

1. Determines the dynamic patterns of humid tropical watersehds in Indonesia.
2. Determines the significantly socioeconomic driving forces of LULC change.
3. Evaluates the population pressure level in the humid tropical watershed.
4. Provides information about the ecological impats of LULC change on land degradation and water quality status.

5. Provides useful information about the sustainability status of the humid tropical watershed.
6. Provides suiTable recommendations for better land management toward sustainability of humid tropical watersheds in Indonesia.

7.4.2 Recommendations

For recommendation, therefore, lasting solutions to the problem of resources degradation in the watersheds and the country level should however a number of practical measures geared toward improving sustainability function of the watersheds such as reducing population pressure on the land, conserving degraded area, conserving forest, promoting development of the non-agricultural economy. Upper watershed, the most fragile segmentation, can be managed by rehabilitation program for degraded areas with agroforesty system. The middle and downstream area, receiver of environmental impacts, can be managed by developing non agricultural economic activity such as the potensial of tourism activy or other possible economic services. There is an urgent need for community education and information awareness about the social, economic, and physical consequences on the impacts of LULC change and watershed degradation, e.g. forest degradation, water polution and soil erosion. The community development adaptation strategies can be developed in accordance to the needs for achieveing sustainable function of the watersheds.

In Batang Merao watershed, the sustainability of watershed depends on the sustainability of environment and life as the most common causes and consequences in the results of HELP indicators. These two indicators are functionally linked. Therefore, a rational and proper policy for the development of land, water and forest resources of Batang Merao watershed must inegratively consider all these two important indicators.

Recognizing the various problems, a policy review and assessment needs to be undertaken by all concerned stakeholders in managing the watersheds. There is also urgent need for regularly evaluating and assessing of existing policies, as well as other programs. Accordingly, integrated watershed management has to be implemented as a standard approach for effective watershed conservation whereas the deforestation rate and population pressure will become a big challenges for sustainabilty of the watershed.

Creating awareness amongst the society concerning optimum and wise use of natural resources, conservation systems, driving forces including population pressure and their respective benefits is vital for sustainable land management and watershed sustainability. Therefore, the local government, watershed manager and responsible sectors in the watersheds should give emphasis in participation of the local communities in conservation activities and decision making.

By summarizing all the mentioned conclusions and recommendations, the most important recommendation for achieving the sustainability of watershed management in Indonesia is the application of WSI method to different planning terms as a tool for evaluating the condition of watershed. It can give an idea of the evolution of the watershed sustainability along the years, helping stakeholders and water managers in the planning and decision-making process, providing for an adaptive management tool. This study was successful in the assessment LULC change and its ecological impacts, and can contribute to decision making and planning in order to achieve sustainability of humid tropical watersheds in Indonesia.

Finally, this research is a kind of pioneer in successfully assessing the sustainability in Batang Merao Wateshed. Therefore, in Indonesia perspectives, what we have done hopefully will be followed by the policy makers related watershed management within their area. To achieve the significant of this research, as my future task is to disseminate this research in front of the related government agencies in Indonesia (Ministry of Forestry, Ministry of Environment, Center of Watershed Management and local government of Jambi Province and Kerinci Regency) so that they can do practical policy regarding the sustainability of the watersheds.

7.4.3 Proposal

In the context of sustainable watershed management, this research contribute in assessing LULC change and the level of watershed sustainability in Indonesia. This assessing is an important part of planning cycle components in the context of sustainable watershed and water resource management (Moriarty et al., 2005; UNEP, 2012b). Having recognized the importance of LULC change research and watershed sustainability in humid tropical watersheds in Indonesia, we offer the following proposal in order to achieve better sustainability and to work toward sustaibility for the watersheds in Indonesia. The two important proposed research demand in response the major findings of this research are designing rapid assessement of watershed sustainability in Indonesia and prioritizing sustainability for protecting humid tropical watersheds in Indonesia. As watershed management is multidisciplinary research, this research offers an open room for collaborative research which involves international bodies, educational institutions, government and any others relevants partnership.

Figure 7.1 Structure of continuing research proposal for sustainability in humid tropical watershed in Indonesia

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My Allah the Almaghty, forgive my sins and failures, and reward me all abundantly.

Higashihiroshima,

Rabi' Awwaal 23, 1435
January 24, 2014

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