AN APPLICATION OF GEOINFORMATICS TO STUDY THE EFFECTS OF LAND USE CHANGES ON STREAM FLOW; A CASE STUDY IN MAE TAENG WATERSHED, CHIANG MAI PROVINCE, THAILAND

THURA WIN HTUN

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Thesis
Entitled

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Thura Win Htun

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A CASE STUDY IN MAE TAENG WATERSHED, CHIANG MAI PROVINCE, THAILAND

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ABSTRACT

Mae Taeng watershed plays an important role in the daily lives of human beings as its attributes and functions are composed of prosperous natural resources providing tangible and intangible benefits. Although the area has been under management for a couple of decades, it was subjected to various human induced changes among which land use was prevalent. To considering the impact of land use change, there were temporal assessments of land use/cover. The impact of land use change on runoff has been recognized as an important factor along with the runoff-rainfall ratio.

The objectives of this study were: 1) to investigate rainfall and runoff in the Mae Taeng watershed, 2) to examine how land use and land cover has changed in the Mae Taeng watershed and 3) to analyze the relationship between land use change and runoff-rainfall ratio. This study has been carried out by using quantitative methods for data analysis of land use changes from 1989 to 2004, runoff and climatological factors such as rainfall. The study utilized geoinformatics applications for analyzing land use and rainfall factors.

The results revealed that annual rainfall in Mae Taeng watershed was within a range of 1000 mm to 1600 mm. While land use assessment revealed forest dominated land declined to 34% from 42%, land use change to orchard was the most common change among other land use types such as paddy fields, field crop, perennial crop, horticultural land, shifting cultivated land, forest, wetland, and community. The results showed that changes from forest to orchard were common and it can be inferred from the results that runoff-rainfall ratio is directly proportional to the forest cover.

It was found from the study that the runoff-rainfall ratio depends on land use change during the study period of 1989-2004. Hence, the study recommends that if suitable land use practices are employed along with the land use change it would be feasible to achieve the goals of sustainable land use through efficient water usage.

KEY WORDS: RAINFALL/ RUNOFF/ LAND USE/COVER CHANGE/ GIS/ GEOINFORMATICS

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CHAPTER 1
INTRODUCTION

1.1 Justification

Thailand is a country with an abundance of natural resources, and particularly Northern Thailand which possesses a large share of forest. However, the area of forest has been covered 26 percent (12.62 million hectare) of Thailand's territory area from maintained 72 (35.38 million hectares) percent of the total area in 1961 (Kaosa-ard, 2000). The dense forest covered the northern watersheds of Thailand was subjected to commercial forestry, population growth, and expansion of agricultural commercialization.

Dating back to forest management in Thailand, forests are managed by Thailand's Forest Act of 1941 (amended in 1948, 1982, and 1989). According to National Forest Policy acted in 1985, 40 percent of total forest area was to be maintained as an objective of this policy. Of this 40 percent, only 15 percent was to be kept as conservation forest area including first class watersheds, national parks, and wildlife sanctuaries. The other 25 percent was classified as economic forest area (Kaosa-ard, 2000).

Forest cover in Northern region was considered moderate in comparison to situations in other parts of the country because the North's predominantly mountainous features made logging activities rather difficult understandings. Nevertheless, the removal of mature timber stands also provided room for forest dwellers to settle into communities in the highlands. As the Northern region received much attention from central government addressing the problem of interregional linkages by investing in many transportation routes and networks in the area, for political as well as economic reasons. The development of such an infrastructure did help to save some of the costs of transporting agricultural commodities, but at the same time it encouraged the

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further exploitation of forest resources. Another factor causing the continual loss of forested land in the region was the demand for the use of the forest area, as it has a pleasant climate and spectacular scenery, for such purpose as tourism and recreation. The increase in this demand, particularly during the bubble economy period between 1987 and 1995, led to speculation and transaction in the hill land 'market', and eventually to the further clearing of forest areas (TDRI, 2000).

In northern part of Thailand, land use practices of local people were relied on regional and national social and economic forces. In the period of 1954-1983, traditional swidden cultivation also called slash-and-burn or shifting cultivation was been practiced by local people. They involves cutting living vegetation in the dry season, letting it dry, burning it late in dry season, and then planting a crop in the early wet season. Declining crop productivity, due to weed competition or soil nutrient depletion, leads to the field being abandoned for 10-15 years after practicing 1-2 years. As long as population density remains low and abandoned fields recover as forest succession proceeds, most swidden cultivators live in the forest in a sustainable basic (Fox, 1995). Timo et al., (2002) recognized that as shifting cultivation has gradually intensified, a various circle of shortened fallows can take place when there is a shortage of land. When fallows are shortened below the minimum length, the forest does not have enough time to recover, resulting in a decrease in the fertility of the clear land. Swidden agriculture known as shifting cultivation became unsustainable under the increasing population pressure, development of markets, enhanced infrastructure, and introduction of monetary economies.

Rapidly, population pressure continued to increase in upper watersheds. Similarly, an integrated approach to highland development in mountainous region or highland areas where opium crop had been prominently grown had been introduced with a poorly emphasized at initial stage on ecological function. With an introduction of new technologies and water using crop into hill tribe people in order to meet greater food and to increase cash in compensation for the loss of opium crop income, ecological impacts became generated problems on soil erosion and declining water yields of highland watersheds.

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From the past up to the present, almost all mountainous watersheds in Thailand had been severely affected by degradation due to land misuse and abuse, then resulting in the loss of functional ecosystem, change in water yield caused by soil erosion problems, landslides and downstream sedimentation, soil fertility degradation through soil erosion and nutrient leaching which subsequently leads to the decrease in crop production, change of stream flow pattern, lack of water supply during dry periods, and increase in flooded areas and flood damages in the rainy season (Mingtipon and Udomchoke, 1999).

The Mae Taeng River Basin occupies an area of 1.900 km^2 along the Thai-Burmese border in Northern Thailand. The basin is a source of water for Chiang Mai water utility system. The Mae Taeng irrigation system supplies water to an area of more than 100,000 km^2 (TDRI, 1995). During the dry season, water from the Mae Taeng River supplies the entire irrigated area. Despite the state's attempts to restore and preserve the basin, only 70 percent of the Mae Taeng's watershed is still defined as natural forest. This change in land use is due to expanding communities in the highlands, the upland small irrigation systems, and the forest plantations that bring about a reduction of available water. The encroachment into the forests leads to soil erosion and a reduced soil capacity for holding and releasing water.

Water loss could be partially attributed to land use change. Significant human activities have been noted in the Mae Taeng watershed for decades and reforestation began as early as the 1960s. At the same time, increased prosperity and convenience induced expansions of human settlements in highlands. All of these have led to increase consumption of water in the uplands and highlands. These land-use changes have affected downstream water users negatively (TDRI, 1995). The previous statistic-based study pointed to the fact that transitions in the nature of land use are the major factors contributing to the loss of available water. These transitions are brought about by expanding communities, irrigated rice cultivation on the highlands and reforestation, (i.e. restoring the degraded deciduous forest by planting pines) (TDRI, 2000).

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In order to assess the impact on stream flow due to land use changes in watershed area where different land use practices have been used for a long time, it is necessary to analysis land use changes which can effect on runoff with the analysis of rainfall and runoff during the period from 1989 to 2004.

1.2 Research objectives

The general objective of this study was to study existing conditions under land-use change that effects on runoff by using Geoinformatics. Therefore, the specific objectives of the study were as follow;

1) To investigate rainfall and runoff in the Mae Taeng watershed
2) To examine how land use and land cover change in the Mae Taeng watershed
3) To analyze relationship between land use changing and runoff-rainfall ratio

1.3 Research questions

The thesis was guided by the following research questions:

1) What is the condition of rainfall and runoff in Mae Taeng Watershed?
2) How is the trend of land use changes from 1989 to 2004 in the Mae Teang watershed area?
3) What type of land use changes has most relation with runoff-rainfall ratio?

1.4 Hypothesis

The following hypotheses were aimed for the thesis.

1.4.1 Land use changes were mostly occurred in forest land to other

1.4.2 Reducing the area of forest related to runoff-rainfall ratio

1.4 Conceptual framework

Geoinformatics was used in this study to interpret the land use and their changing in Mae Taeng Watershed, Chiang Mai Province. Quantitative research method was used to ensure reliable results. The study aimed to assess the effect of land use change on runoff and to tackle some constraints existing in watershed management.

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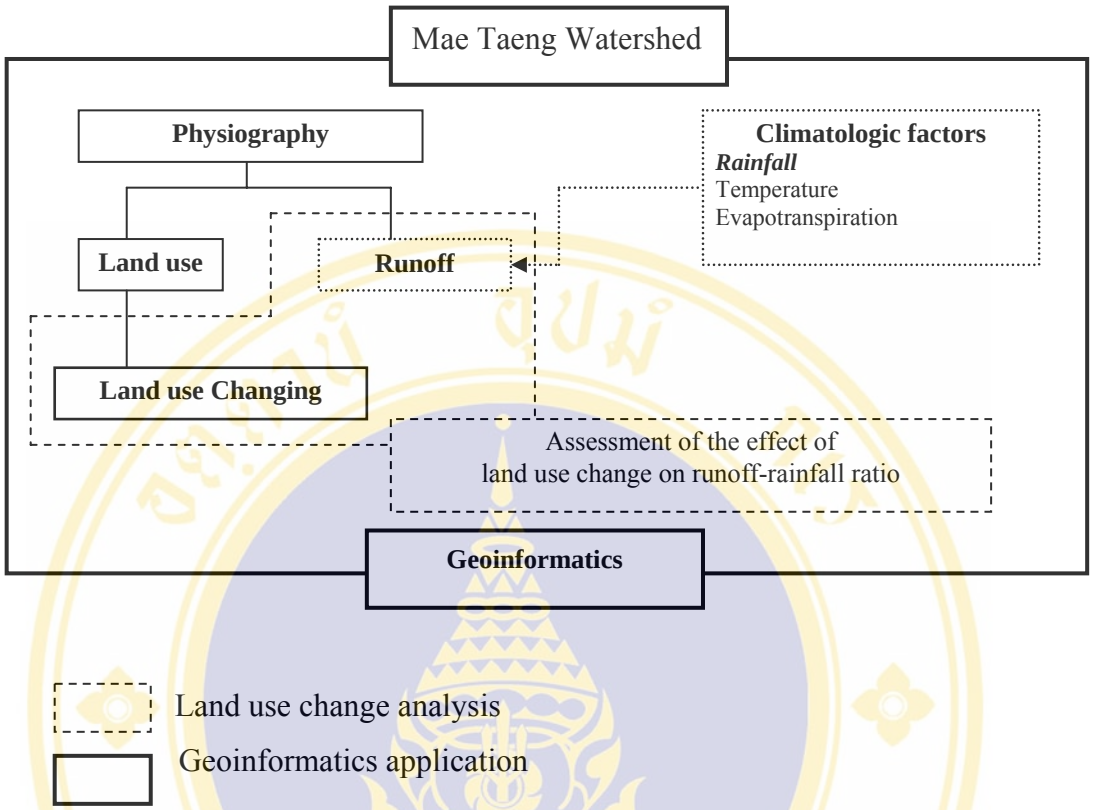

Figure 1.1: Conceptual framework for impact of land use change on runoff-rainfall relationship

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CHAPTER 2
LITERATURE REVIEW

The aim of this chapter is to review the back ground information of the study area, the classification of land use, the reason of how land us change related to water resources, the impact of land use change on water quantity as well as the application of geoinformatics that was used to assess the changes of land use in the study area. Therefore, literature concerned with land use change and its impact on runoff has been reviewed in the following sections.

2.1 Mae Taeng Watershed: Study area

2.1.1 Location

Mae Taeng River (Mae Nan Mae Taeng) is a tributary of the Ping River (Mae Nan Mae Ping). The Nam Mae Taeng flows in a dominantly north-south direction from its headwaters on the Thai-Myanmar border (Grid Reference 790864, Sheet 4748) to its confluence with the Nam Mae Ping, some 35 km north of Chiang Mai. The river is 120 km in length, falls 1300 m and drains an area of approximately 1,953 km^2 extending between latitude 19 05’ to 19 45’ N and longitude 98 28’ to 99 00’ E. It is flanked on the western boundary by the smooth rounded summits of granitic mountains such as Doi Chang (1,962 m) and Doi Sam Mun (1,725 m), while the eastern boundary is dominated by angular, limestone massif of Doi Luang Chiang Dao (2,175 m), the third highest mountain in Thailand.

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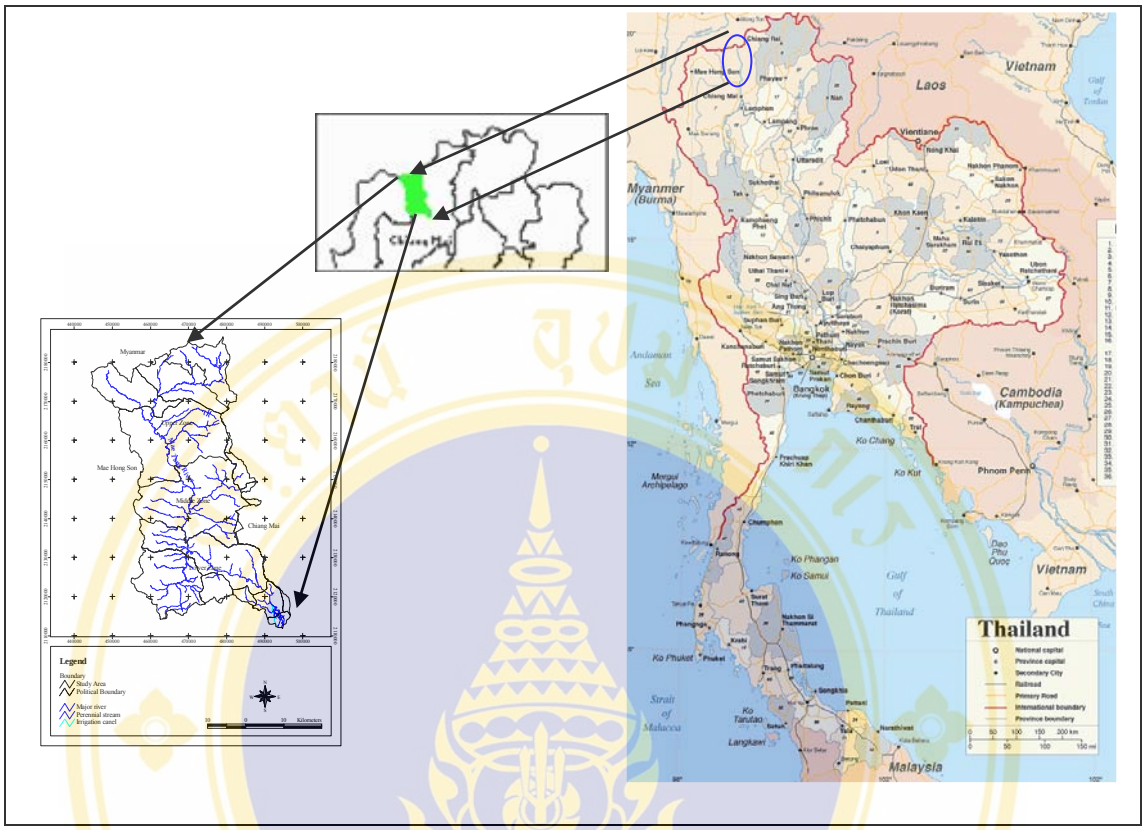

Figure 2.1: Location of Mae Taeng watershed area

2.1.1 Geology

Most watershed areas are mountainous. They consist of various rocks in different areas. Most rocks are igneous rock in the form of granite and granodioride. Some rocks are mostly seen in the south. But granite and granodioride are found in the northwest. They are occurred during the end of Cyrulian and the beginning of Carboniphorus. The sedimentary and metamorphored rocks are found in the middle part up to the north. These rocks are during Carboniphorus and Tertiary. Most of them are sand stone, gravel and shale.

2.1.3 Climate and precipitation

The Mae Taeng watershed is within the tropical monsoon zone, with main influences from the southwest monsoon in mid-May to mid-September, the northeast monsoon from mid-October to mid-February, and also from cyclonic storms and inter-tropical

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fronts. The effects of this are to give a notably seasonal variation in climate with abundant precipitation associated with the southwest monsoon and a relatively dry northeast monsoon.

2.1.4 Soil

According to Soil Survey Division of Department of Land Development, the soil series in Mae Taeng Watershed includes 14 different classifications such as Lampang series, Lat Ya series, Tha Yang series, Tha Yang/ Lat Ya association, Hang Dong series, Korat series, Hang Chat series undulating phase, Mae Rim series undulating phase, Mae Rim series rolling phase, Mae Taeng series undulating phase, Pak Chong series undulating phase, Alluvial complex, and Slope complex. However over 90 % of the area is classified under soil type "slope complex"

2.1.5 Vegetation cover

There still remain Dry Dipterocarpus and Moist Deciduous forests at the head of plains, a distinct northern facies of the Seasonal Evergreen Indochina Dipterocarp forests, vast oak-laurel submontane forest, pine savannas and subtropical mountain grasslands resplendent with temperate wildflowers. Vegetation distribution in Mae Taeng can be recognized as a basic distinction between deciduous and evergreen vegetation, a reflection of seasonally dry, monsoon climate of the area. Depend on two paramount ecological factors; soil moisture availability and elevation, range of vegetation types vary from the most xeric, deciduous dipterocarp, through the tropical mixed deciduous forest to evergreen forests on the wettest sites. In terms of elevation, two main zones can be recognized, lowland and montane. Vegetation below at 1000 m level is being dominated largely by elements of tropical lowland forests such as *Annonaceae*, *Dipterocarpaceae*, and *Myristicaceae*. Above this altitude the vegetation is dominated by temperate families such as the *Betulaceae*, *Fagaceae* and *Mangoliaceae*. A further transition takes place at about 1800 m, the mist belt, lower and upper motane forest.

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2.1.6 Land use

Mainly, land use types were classified as paddy field, field crop, perennial crop, orchard, horticultural crop, shifting cultivated land, forest, wetland, and community.

2.2 Water resource

Water is the most important services revolving around water supply: providing a sufficient quantity of water for domestic consumption and agriculture, maintain high water quality. But fresh water ecosystems provide many other crucial goods and services as well: habitats for fish, mitigation of floods, maintenance of biodiversity, assimilation and dilution of wastes, recreational opportunities, and a transportation route for goods (WRI, 2000). Scientists estimated the average amount of runoff worldwide to be between 39,500 km^3 and 42,700 km^3 per year. In fact, only about 9,000 km^3 is readily accessible to human, and an additional 3,500 km^3 is stored by reservoirs (WRI, 2000).

2.2.1 Water resource problem

Water is, in theory, a quintessentially renewable resource. Most of the world's surface is covered in water and over much of the world it falls, unbidden and with great regularity, from the skies. Yet, the carelessness and profligacy with which water resources have been used, the speed of human population growth and the increasing per capita demands for water together mean that provision of a adequate, safe supplies of water is a major source of concern, expense and even international tension (WB and WWF, 2003). The impacts of land use on water resources depend on a host of natural and socio-economic factors. Natural factors include climate, topography and soil structure. Socio-economic factors include economic ability and awareness of the farmers, management practices, and the development of infrastructure, e.g. roads (Kiersch, 2002).

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Forest clearing for agricultural development generally results in rising groundwater level and increased stream flow volume and discharge. The rate of rise depends upon the environmental settings of the catchment. The rate of groundwater level rise decreases with decreasing annual rainfall so groundwater takes longer to reach the streambed. Stream salinity increases dramatically with decreasing rainfall once the groundwater level reaches the streambed (GWA, 2003).

Water resource problems are mostly related to agriculture, industry and settlement activities. Moreover, the type of forest management has significant impact on water qualities which have generally shown that sediment yield increases after timber harvesting. Water quantity, flow of water from catchment is more complex due to reason of the precise interactions between different tree species and ages, different soil types and management regimes. Especially, the impact of land use on runoff depend on many variables, the most important being the water regime of the plant cover in terms of evapotranspiration, the ability of the soil to hold water (infiltration capacity), and the ability of the plant cover to intercept moisture. In case of planting new forests, particularly of species with high evapotranspiration rates, can often lead to reduced water flow (WB and WWF, 2003).

2.2.1.1 Water quantity problem

Forest cover affects the total amount of water available in a watershed. In 1998 an analysis by WRI found that nearly 30 percent of the world's major watersheds had lost more than three-fourths of their original forest cover, and 10 percent have lost more than 95 percent of their original forest cover. In the tropics, montane forests are under even greater pressure. Tropical forest loss will in crease net water discharge because less water is transpired to the atmosphere (WRI, 2000).Chang (2003) stated that water demand is described as either water withdraw or water consumption. The term withdraw refers to pumping or taking water a source for various uses or storage. Water consumption or consumptive use of water refers to the part of withdraw water that is vaporized to air, consumed by humans, plants or livestock, incorporated into products, and not discharged into a supply source for potential reuse. According to World

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Resources (2000-2001), agriculture is perhaps the most significant human influence on the world's water cycle, affecting quantity, timing, and quality of water available to freshwater system. At a global scale, agriculture accounts for the greatest proportion of total freshwater withdrawals of any sector of human activity (WRI, 2000).

2.2.1.2 Water quality problem

Forests in watershed area retain water in soil, regulate flow, influence precipitation, and filter drinking water. Forest loss in general has eroded the capacity of the world's forest to protect watersheds and provide water-related services, and also threaten high economic value of water purification service in certain region. Both irrigated and rain-fed agriculture can pose threats to water quality from the leaching of fertilizer, pesticides, and animal manure into ground or surface water. Sediment from erosion can also greatly degrade surface water quality. Irrigated agriculture also creates problems associated with excess water in the soil profile: water logging and salinization (WRI, 2000).

2.2.1.3 Factors affected on water resource

During the recent decades natural variations in river runoff and quantitative and qualitative characteristics of renewable water resources have been much affected by a whole complexity of anthropogenic impacts. They include those related directly to water intake from river systems for irrigation, industrial and domestic water use. They are also including reservoir runoff control, river basin land use change such as afforestation, field management, urbanization and drainage. All these factors differently affect the total volumes of water resources, river runoff regime and water quality (UNESCO, 2000).

Moore (1999) stated that the connection between forests and water is complex and varies with topography, geology, climate and vegetation. Forest management practices, even upland forestry activities can impact water quality and hydrology through runoff, stream flow, infiltration or other means. Trees store some water, but

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mainly act as pumps, removing water from the soil through their roots, and returning it to the atmosphere through their needles or leaves--a process known as transpiration. As removing of the tree and other plants during a harvest operation, it can have a significant impact on the water relations on a site. Because, when the transpirational pump is removed, there is a resulting temporary rise in the water table-usually in proportion to the amount of canopy removed.

Plant cover, through the unique effects of its canopy and root systems on precipitation interception, infiltration, percolation, surface detention and roughness, transpiration, snow accumulation, and snowmelt, is a very important factor in the hydrologic cycle. Forest cutting usually results in an increase in water yield. Converting natural vegetation to rainfed agriculture (including shifting cultivation) increase water yield: vegetation cover, and therefore transpiration, is typically lower under rainfed agriculture. The effect of clear cutting on water yield can be estimated by changing the effective rooting zone in the soil system after clear cutting and recomputing the water budget (PRTC, 1981).

Catchment experiments involving a manipulation of canopy cover, such as afforestation or deforestation/harvesting, were found to produce different effects on stream flow, depending on plant species, climate and other variables (Newson, 1992). Moore (1999) explained that with a full canopy, an average of 20% of the precipitation is intercepted by the needles, leaves and branches where it evaporates, never reaching the soil for infiltration. Following harvesting, the lack of canopy allows more water from rain and other forms of precipitation becomes surface water. At this time both surface runoff and groundwater flow increase in duration and amount.

The form of land degradation across a watershed may result in the rapid concentration of surface run-off and increased susceptibility to flood hazards and landslides. Alternatively, other kinds of land –use change can alter run-off behavior by reducing the amount of long-term flow in rivers and streams and so increasing the severity of droughts (UNESCAP, 1997).

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2.3 Land cover and land use

Land is a delineable area of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface including those of the near surface climate the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the near-surface sedimentary layers and associated ground water reserve, the plant and animal populations, the human settlement pattern and physical results of past and present human activities (terracing, water storage or drainage structures, roads, buildings, etc) (FAO, 1995).

2.3.1 Land-use classification in the world

Land use is defined as the observed physical cover including the vegetation (natural or planted) and human constructions which cover the earth's surface. Water, ice, bare rock or sand surfaces count as land cover (Di Gregorio and Jansen, 2000).

Land use can be defined as the use of land by humans, usually with emphasis on the functional role of land in economic activities. FAO (1995) states that "land use concerns the function or purpose for which the land is used by the local human population and can be defined as the human activities which are directly related to land, making use of its resources or having an impact on them". In another word (Campbell, 2002) stated that land use is associated with specific economic activities and land-use categories. There are one or more objective in using of land belonging to different structure and function of it. Land use corresponds to the socio-economic description (functional dimension) of areas: areas used for residential, industrial or commercial purposes, for farming or forestry, for recreational or conservation purposes.

Land is used to meet a multiplicity and variety of human needs and to serve numerous, diverse purposes. When the users of land decide to employ its resources towards different purposes, land use change occurs producing both desirable and undesirable impacts. Depend on different purposes, land use classification systems are tied usually

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to particular spatial scales but they reflect also functionally-defined scales such as the scale of agricultural or industrial organization. At the world level, the FAO distinguishes four or five major land use types. At the level of nations, the number of land use types increases to around ten. At this level, other scales enter the classification system to differentiate further the land use typology – agricultural land is further subdivided according to the type of product (annual, perennial), pastures are distinguished according to ownership status into public or private, etc. At the level of a parcel of land, land use classification becomes very detailed capturing local environmental, socio-cultural, demographic, economic and other details (Briassoulis, 2000).

2.3.2 Land-use/cover change

Briassoulis (2000) recognized that the meaning and conceptualization of land cover and land use change is much broader. There are two type of changes: conversion and modification. Land cover conversion involves a change from one cover type to another. Land cover modification involves alternations of structure or function without a wholesale change from one type to another; it could involve changes in productivity, biomass, or phenology. Land cover changes are the results of natural processes such as climatic variations, volcanic eruptions, changes in river channels or the sea level. However, most of the land cover changes of the present and the recent past are due to human actions; i.e. to uses of land for production or settlement.

2.3.2.1 Factors affected on land-use change

The Asia and Pacific region covered about 23 per cent of the total land area of the Earth has been occurring with critical land issues of degradation, land use change and soil contamination due to major driving forces of population growth and high population density, poor land management practices, and emerging inequities in land and resources assess for over the past 30 years (UNEP, 2002). As part of highly complex ecosystems, including watersheds, mountain forests capture and store rainfall and moisture, maintain water quality, regulate river flow, reduce erosion and protect

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against landslides, avalanches, falling rocks and floods. In many mountain areas, especially mountain forests provide Non-wood Forest Product (NTFPs) and recreational facilities and add to the scenic beauty of landscapes, national parks and protected areas. On the other hand, the vitality of these forests are reduced and their protective function impaired due to high demand for fuelwood and agricultural land, unsustainable forest practices and the excessive granting of timber concessions (FAO, 2003).

Tropical region stores huge values of natural resources on which a majority of the population rely on these for food and other products. With substantial improvement in the level of incomes and welfare of the societies, demand for settlement increase substantially, improvement in agricultural technology, demands investment in agricultural technology, demand investment in agricultural infrastructure and facilities, forest cutting through logging and mining concessions, and many other activities altered the earth surface; most likely from the previously optimal ecological systems to one that would lead to imbalance environment and living space (Karsidi, 1998). Moreover, alternation of land cover due to human land uses and activities at unprecedented rates, magnitudes and spatial scales is one of the major elements in environmental changes. Similarly, with the problem of land use changes, consequent of that factor, the three major factors causing increasing water demand over the past century are population growth, industrial development and the expansion of irrigated agriculture (UNEP, 2002). As existing development and increasing population limit options for use of land resources, development may be attracted to sites of marginal suitability or cause displacement of activities from their optimum sites (Campbell, 2002).

2.3.2.2 Related studies about impact of land-use change on stream flow

Effects of land use changes on runoff characteristics of a watershed have been studied using several types of models. Among them, Vanliew (2003) studied how potential changes in land cover affect water quantity for watershed in the Southern Great Plain, USA using the Soil and Water Assessment Tool (SWAT) to determine the variations

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in stream flow associated with various hypothetical changes in land cover. In that study, he intended to compare the impact of changes in land cover on hydrologic response under dry, average, and wet climatic conditions.

Klocking and Haberlandt (2001) conducted a study impact of land use change on the water balance in meso and macroscale river basins. In that study it can be proved that simple approaches are needed to setup possible land use changes in the basis of easily available spatial data using the mathematical modeling system ArcEGMO in hydrological simulations. The result showed that land use impacts on extreme flood events are small. Land use changes affect mainly the water availability.

Barkhordari, (2003) has conducted an alternative approach to ascertain actual changes in hydrologic response of a particular watershed to land use transformations made in the past. The alternative rapid approach, as applied here to the Minab catchment in the South of Iran, includes the analysis of long-term historical time series of data on rainfall, land use and stream flow, to distinguish changes in the watershed and their effects on the hydrologic regime. This study showed the land use changes using multitemporal analysis of satellite image must be responsible for the decrease runoff generation process during the period of conversion of natural cover to overgrazing, rangeland between 1986 and 2002 as revealed by analysis of annual rainfall-runoff relations.

Verbunt et al, (2005) studied that the hydrologic impact of land cover changes Swiss Alpine Rhine basin, by collecting reservoir level data, an attempt has been made to incorporate release and storage mechanisms of hydropower plants into hydrological modeling. Results from analysis using Water Flow and Balance Simulation Model can show that urbanization may have a significant impact on local flood events, changing grasslands into forests results in an increase in evapotranspiration, especially at the valley bottom and decline in runoff is dependent on the decrease of soil and root depths with increasing altitude.

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2.4 Watersheds management

A watershed is an area of land that captures water in any form, such as rain, snow, or dew, and drains it to a common water body, i.e., stream, river, or lake. All land is part of the watershed of some creek, stream, river, or lake. The watershed boundary is defined by the higher elevations or ridges that define with direction the rainwater will flow (Debarry, 2004).

There are three processes; capturing water, storing water and releasing it safely, in a watershed as the land on which water falls from the atmosphere and in which that water is stored underground and then released to other locations over a period of time. Capture means the process of water from the atmosphere getting into the soil through infiltration and percolation. However, vegetation structure and the density of plant are the important factors in determination of infiltration rate. Especially, plant cover can reduce raindrop impact upon the soil surface and minimizes soil crusting as well as plant litter and organic matter on and incorporated into the soil surface to absorb moisture and help maintain soil structure. On the second function of watershed, storage of water in soil is also affected by vegetation and plant community. Especially, soil moisture is lost through plants that grow on the site and through direct evaporation from bare soil surfaces. As the last function of watershed, safe release of water movement through the soil profile to seeps, springs, and ultimately into streams and rivers is directly affected in case of the form and amount of vegetation growing in the various riparian zones strongly and directly affects on both the quality and the quantity of timing of water moving through the soil (Barretts, 1991).

Watershed management is an approach in order to properly manage a watershed with a goal of to maintain the hydrologic budget. However, watershed management is based on the comprehensive picture or holistic approach to ensure sustainable water resources with comprehensive management of many facets of water, including water supply, stormwater management, flood control, nonpoint pollution control, and waste water treatment and reuse. Therefore, watershed management is a broad and wide-ranging effort that encompasses activities such as identifying and delineating source

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water protection areas, minimizing discharges, and managing stormwater. Zoning and land use regulations and growth management techniques are effective mechanisms for directing development to areas that can support it. Knowledge of the relationships between physical catchment properties and hydrological response characteristics allow us to understand and perhaps quantitavely predict how a change in physical properties of a catchment will affect its hydrological response (Mwakalila, 2002).

2.5 Geoinfomatics

Geoinformatics: Geoinformatics can be though as the field in which geoscientists and computer scientists are working together to provide the means to address a variety of complex scientific questions using advanced information technologies and integrated analysis (PACES, 2003).

Geographic Information Systems: Geographic Information Systems is a tool used to gather, transform, manipulate, analyze, and produce information related to the surface of the Earth (Günther, 1998).

Remote Sensing: "The term Remote Sensing means the sensing of the Earth's surface from space by making use of the properties of electromagnetic waves emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resources management, land use and the protection of the environment" (UN, 1986).

2.5.1 GIS

GIS consists of five key components; hardware, software, data, people and method. Normally, it consists of the computer system (hardware) on which the GIS software will run. The hardware system ranges from the backbone of the GIS hardware through the scanner or a digitizer and printer. GIS software provides the functions and tools needed to store, analyze, and display geographic information. Geographic data and related tabular data can be collected to integrate a spatial data with other data resources. There are different models and operating practices unique to each

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organization with the use of various techniques for map production and further usage for any project.

GIS are computer-based tools to capture, manipulate, process, and display spatial or geo-referenced data. Geographic data is a special and important type of environmental information. With regard to data capture, GIS provide software support for digitizing analog map data. For data storage, GIS used to rely exclusively on customized file system solution. GIS used layer-based model in which information is encoded in a number of thematic maps, such as vegetation maps, soil maps, or topographic maps. Moreover, GIS can assist data analysis in a way of intersection different map layers and aggregating the available data (Günther, 1998).

2.5.2 Remote sensing

Remote sensing systems consist of four basic components; target, an energy source, a transmission path, and a sensor. The target is the object or material that is being studied. The components in the system work together to measure and record information about the target with actually coming into physical contact with it. There must be an energy source which illuminates or provides electromagnetic energy to the target. The energy interacts with the target, depending on the properties of the target and radiation, and will act as a medium for transmitting information from the target to the sensor. The sensor is a remote device that will collect and record the electromagnetic radiation. Sensor can be used to measure energy that is emitted by the target, reflected off of the target, or transmitted through the target (CGIS, 2004). Once the energy has been recorded, the resulting set of data must be transmitted to a receiving station where the data are processed into a usable format, which is most often as an image. The image is then interpreted in order to extract information about the target. This interpretation can be done visually or electronically with the aid of computers and image processing software.

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2.5.3 Integration of geoinfomatics to study land use change and runoff

Geoinformatics is the application of information technology to earth science. With a new age has dawned in scientific and engineering research, overarching finding has pushed by continuing progress in computing, information, and communication technology, and pulled by the expanding complexity, scope, and scale of today's challenges. Therefore, Geoinformatics aims to allow seamless interconnection of databases and to incorporate: acquisition and long-term maintenance of analog and digital legacy data; efficient information and data retrieval mechanisms (via data mining and web services); dynamic on-the-fly data compilation and presentation; accessibility to and application of visualization, analysis, and modeling capabilities; online workspace, software, and tutorials; GIS; integration with online scientific journals and digital libraries; distributed network of digital geo-libraries; access to real time data collection and dissemination; user-defined automatic notification and quality control filtering; and application to field techniques (Allison, 2003).

Remote Sensing, in combination with global positioning systems, allows large amounts of environmental data to be acquired and geo-referenced together with the opportunity of repeated runs which could build up a time-series of events (O'Callaghan, 1996). Preparation of a land use change assessment requires comparison of multitemporal land-use maps prepared from imagery acquired at different time interval. Technology of remote sensing (RS) and Geographic Information System (GIS) had opened the opportunity to monitor changes in the land use and land cover in much higher accuracy and allow for more rigorous analysis as to what extent the driving forces (socio-economic, population and demographic factors, etc) (Karasidi, 1998).

Technologies for mapping and land resources management provide scientists with automated tools for extracting and evaluating spatial information. Remote sensing and GIS allow extraction, manipulation, analysis and generation of tabular and graphical representations of information about the earth's surface even without actually collecting field survey data (Alba.J., et al 1998). As GIS is a set of tools for collection

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storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular purpose, it was rapidly becoming a standard tool for management of natural resources with the efficient use of large spatial data volumes depending upon the existence of an efficient geographic handling and processing system to transform the data into usable information (GIS Development, 2005).

Rana, (1999) studied that Rainfall-runoff modeling using NAM model that is used for daily flow forecasting in the Chiang Mai Subbasin of Ping River in Thailand. In that research, an application of Geographic Information System (GIS) provide required information for initial estimation of the NAM model parameters for a realistic analysis of runoff from watershed. Thus, using GIS which contains computer database concept and computer cartographic technology to establish the watershed geographic database is able to provide both fast and accurate results on watershed hydrologic parameters.

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CHAPTER 3
RESEARCH METHODOLOGY

The chapter intended to describe the research methodology in which estimation of required rain gauge stations for study area, annual rainfall estimation for runoff-rainfall analysis, and land use map processing and land use change analysis to analysis the relationship between land use changes and runoff-rainfall ratio.

3.1 Research design

This study used the Geoinformatics determining land use change in term of which types of land use changes has effect on runoff-rainfall ratio in Mae Taeng watershed. A quantitative research method was used such as rainfall-runoff analysis and land use change study. The detail was as shown in figure 3.1. The data set of runoff, rainfall, and satellite images were applied in order to analyze relationship between land use changes and runoff-rainfall ration. Geoinformatics process to assess the land use changes based on temporal satellite images and to estimate annual rainfall using Thiessen method was effective method for this study. With the application of geoinformatics in the process of land use change and rainfall analysis, statistical analysis were been conducted to explain the relationship between dependent variable (runoff-rainfall ration) and independent variable (land use changes).

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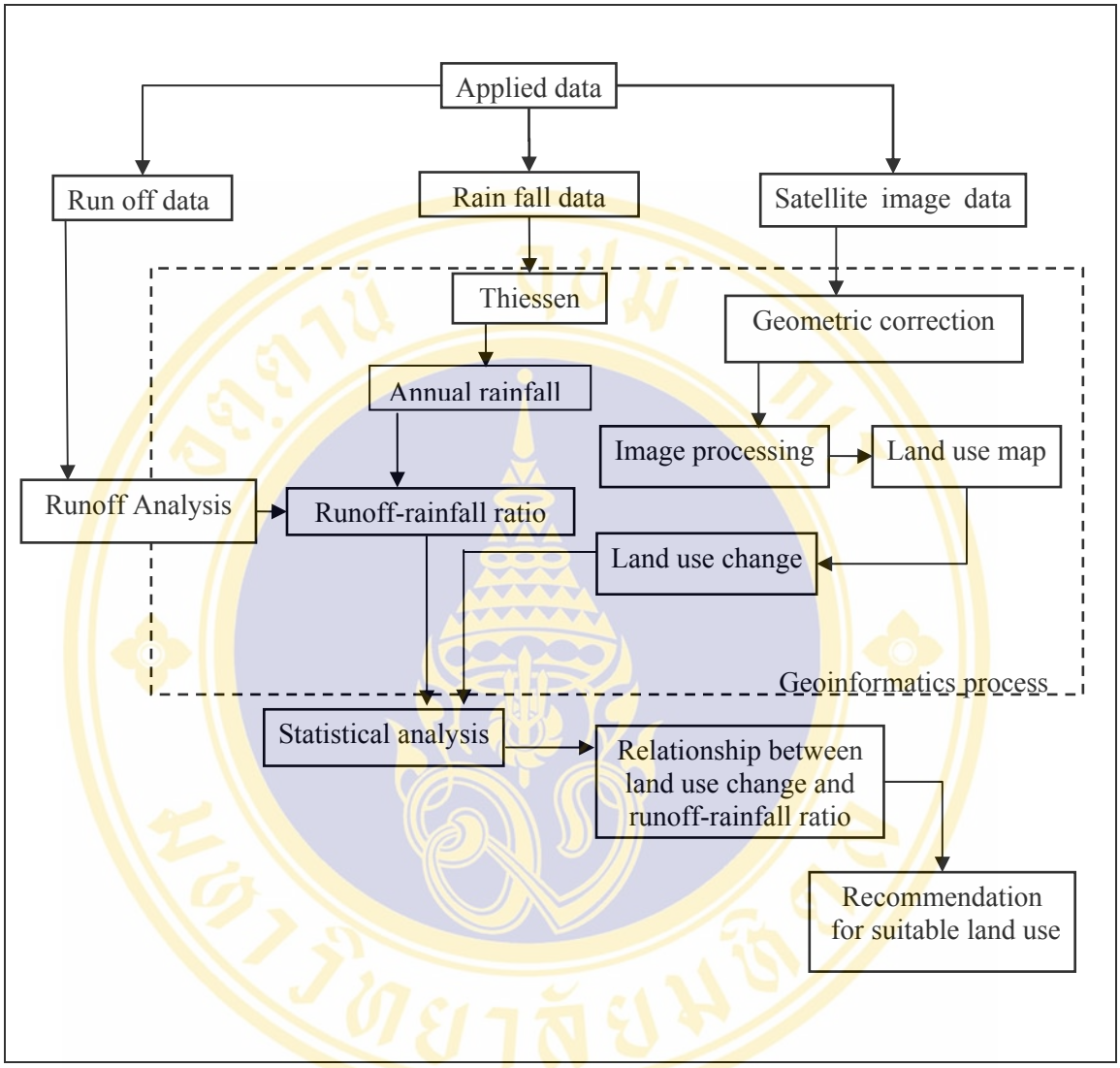

Figure 3.1: Steps of rainfall-runoff analysis and land use change study

3.2 Materials

The following materials of this research were included in analysis of data required for land use change and runoff-rainfall relationship.

1) Topographic map

2) GIS database

3) Satellite images data

4) Runoff data

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5) Rainfall data

6) Personal computer and printer

7) GIS software: Arc View GIS Version 3.3

8) Image processing software: ERDAS IMAGIN 8.6

9) GPS

10) Digital camera

3.3 Data requirement

As data requirement in analysis of land use, rainfall, and runoff, the requirement of primary and secondary data were included in this study.

3.3.1 Primary data

Field surveying to recheck the land use in study area had been done after image interpretation. In order to do ground verification in the study area whether the classification of land use represent the real situation, the collection of points for each class was conducted based on the 2004 image data using GPS. In conducting field check, the collection of GPS points was carried out from the upstream to down stream of the Mae Taeng watershed.

3.3.2 Secondary data

The following secondary data were required to carry out the research in related process.

a) Topographic map of the scale 1:50,000 of series L7017 consisting of the study area from Royal Thai Survey Department (RTSD)

b) GIS database from Department of Environmental Quality Promotion

c) Satellite images data: LANDSAT TM (1989) (1995) (2000) (2004) from Geo-informatics and Space Development Agency (GISTDA)

d) Hydrological data: monthly runoff data from Royal Irrigation Department

e) Climatologically data: monthly rainfall data from the Royal Irrigation Department

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3.4 Methodology

3.4.1 Rainfall data analysis

The rainfall data analysis was considered based on two methods, namely, estimation of requirement of rain gage stations and annual rainfall estimation.

3.4.1.1 Requirement of rain gage stations

Precipitation data had been selected as main component influenced on runoff in Mae Taeng Watershed. The analysis on rainfall focused on requirement of rainfall stations for the study area as well as estimation of annual rainfall that represented as the actual rainfall distribution in Mae Taeng watershed. The analysis of rainfall data from 1989 to 2004 was carried out using Excel software. In rainfall data analysis, monthly rainfall was used to get yearly rainfall for each year. According to Barkhordari's (2003) simple statistical equation, that was used to know how many rain gauge stations are required for the study watershed area. The result explained three stations were required in study area.

$$N= (Cv/E)^2$$

Where:

Cv**:** Coefficient variable rainfall area based on available stations and data

E: Percentage of permissible error in area average rainfall estimation

N: Numbers of required rain gage stations

P: Average rainfall of area

$\overline{P} = \sum P/n = 1208.85$

$\overline{P^2} = \sum (\overline{P}/n)^2 = 1461318.32$

S=213.38

$CV=100S/\overline{P}=100*213.18/1208.85=17.63$

$N= (Cv/E)^2 = (17.63/10)^2 = 3.11$

Rain gauge stations requirement is three for Mae Taeng watershed area based on 10% possible error.

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In this research, a rainfall data set mentioned monthly rainfall data was collected for 16-year period in order to calculate the requirement rainfall data. From four rain gauge stations, namely, Wiang Haeng, Mae Taeng, Doi Chiang Dao Watershed Research, and Fang rain gage stations, average monthly rainfalls throughout the year from 1989 to 2004 were applied to get annual rainfall.

3.4.1.2 Annual rainfall estimation

In order to express any correlation can exist between annual rainfall and altitude, annual average rainfall for 16 years of rain gage stations in different altitude. Rainfall point data collected from rain gage station cannot be represent to an area depth of rainfall. There are different schemes of interpolation; selection of appropriate one depends normally on the density of gauging stations in the area, the nature of the area, the objective of study and the availability of time and computing resources. Although the Thiessen method was purposed for the area where gauging stations in the area are few, the area is plain as well in which the influence of topography on spatial distribution is insignificant, Mae Taeng watershed where most of the area were distributed with eventually mountainous. Owing to these the nearest neighbor interpolation method, which is also called Thiessen polygon method has been employed for areal estimation of over the catchment area. Among the various methods, a suitable approach to calculate the area depth, isohyetal method, and Thiessen methods will be applied in annual rainfall calculation.

The Thiessen method has been used areas subdivided into polygons to achieve a weighted average. To develop the polygons a line was drawn between a station and its immediate neighbors. Each line was then bisected with a line perpendicular to the first. This line continues until it reaches the next bisector. This process continues until each station was surrounded and the basin is covered with the polygons. Finally, the area of each polygon was multiplied by the amount of rainfall at the station it surrounds, the results were added, and the sum was divided by the number of stations.

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Of the annual rainfall analysis method, Thiessen was applied to estimate rainfall stretch over the Mae Taeng Watershed. As a first step of Thiessen, calculation of annual rainfall from rain gauge stations surrounding in Mae Taeng watershed and setting of location for those stations were carried out using the Excel. In this process, annual rainfall from 11 stations was used to create Thiessen polygon for the study area with the application of Arcview version 3.3. From the created polygons based on 11 stations, the representative area was clipped from the entire Thiessen polygon according to the watershed boundary. As four polygons included in study area, the annual rainfall of each station in Mae Taeng Watershed is multiplied by area of each polygon that exist in watershed boundary. The value from multiplication of annual rainfall and station polygon is divided by the area (km^2) of the study area after sum the multiplication values.

3.4.2 Runoff data analysis

In term of hydrological data, this research use only runoff data. Runoff is the most important factor in determining the effect of land use change on stream flow. Especially, runoff may vary depend on precipitation as well as land use type in the watershed. Runoff is on of the most essential data set in consideration of stream flow regime in watershed area. Regarding to changes in land use and land cover and climatologic factors, runoff vary in term of period and flow duration through from 1989 to 2004.

3.4.2.1 Annual rainfall-runoff analysis

Being runoff is directly proportional to the rainfall, the ratio of the annual rainfall (mm) calculated using Thiessen method form four rain gage stations and magnitude of runoff (mm) collected from runoff station which covered by the area of 1902 km^2. The ration of rainfall-runoff was used in relationship between land use changes from each land use type to others using statistical analysis.

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3.4.3 Land use data

In this case, the data was acquired from GISTDA and image data was interpreted by using image processing process. The main data used in the research included LANDSAT TM satellite image from 1989 to 2004 in application of remote sensing system specially designed for observation of the earth's surface to collect information concerning topics such as crops, forests, water bodies, land use. Satellite image data have valuable characteristics due to their multi-spectral characteristics, which could be used to provide a lot of quantitative information on land use and vegetation cover. Generally, as an image data was a record of the energy reflected from earth features in a digital format, the data in a remotely-sensed image was based on the actual received energy with minimal interpolation. Therefore, the characteristic made the remote sensing images different from the human eye and other images that were taken by film and digital cameras. As a result, without any image enhancement, it is difficult to interpret remote sensing imagery.

In the context of image processing, as remotely sensed data was uncelebrated in some or all dimensions of the date (spatial, temporal); those data was corrected prior to information extraction. When the images had been obtained from satellite, these were been georeferenced with the use of topographic map to Universal Transverse Mercator of the earth's Globe. Then, the process of rectification was been done in order to transform image data to create an image oriented to map coordinates in a specific map projection. Then, what is the trend of land use change from 1989 to 2004 in the study area. In this study, the image analysis was as follow:

3.4.3.1 Image pre-processing

The detail explanation in image pre-processing described as step by step. In this process, they were geometric correction, image subsetting, image processing, identification of training area, spectral signature analysis, and supervise classification.

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a) Geometric correction

In this study, a remarkable point, such as a junction, from topographic map was been chosen for registration new UTM coordinate. Because a raw digital image contains geometric distortion from producing processes so significant that they can not be used for processing. The causes of distortions may range from variation in the altitude, attitude, and velocity of the sensor platform, by factors such as earth curvature, atmospheric reflection. In orders to fix the problem, geometric correction was been implied. In the process of this correction, the co-ordinates of each cell in the corrected output grid are transformed to determine their corresponding location in the original input (uncorrected image) grid.

b) Image subsetting

To fit the study area into scope and better visualization, unrelated area has been rid of the image. Therefore, extracting an image to get watershed area based on a watershed boundary was carried out in this stage. Elimination of extraneous data from large file into small file that can help in the process to speed up was done in subsetting stage.

3.4.3.2 Image processing

In this study, the method for image processing will be image classification. It will be used with the aim of delineation of land use types. By classification of major land use: paddy field, field crop, perennial crop, orchard, horticultural land, shifting cultivated land, forest, wetland, and community.

a) Identification of training area

The aim of training was to obtain a set of spectral data which displayed in a varieties form of composite false color. The similar representative color was been selected randomly to produce a homogeneous class. Each of which is represented as same main

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ground land cover. In order to assign pixels from image as their representative land use type, the pixels for each class were categorized (figure 3.2).

b) Spectral signature analysis

After defining an unknown pixel, the next step was to find out meaning of each representation. As the suspect areas were being without field observation, spectral signature analysis was performed with application of existing land use map.

c) Supervise classification

The supervised classification was performed with the method of maximum likelihood. The objective of maximum likelihood was to delineate a given pixel to the class that generated from the spectral signature analysis. Randomly re-check was carried out by field observation convincing the correct classification.

The study used a supervised classification approached to produce a final classification map for each image. Training areas were chosen on the knowledge based on the previous land use classification on the study area. Using the signature sets derived from the training areas, different combinations of bands were evaluated to give the best spectral separability for signature sets. For the 1989, 1995, 2000 and 2004 images the best band combination was 3, 4, and 5. These bands were used in supervised classification of each image.

The land use classification for each image based on multispectral classification. Multispectral classification is applied to investigate the information about the known distribution of classes to initiate the processes. From the image class known in some area of the image, the knowledge is used to define training data for each class of interest. For the entire image in study area, polygon that enclosed particular pixel group was drawn. If the pixel is within a particular polygon, it is assigned to the corresponding class. While the pixel at specific named class was been assigned to its class name, support as the pixel at *a* could be assigned to A. The polygon allocation

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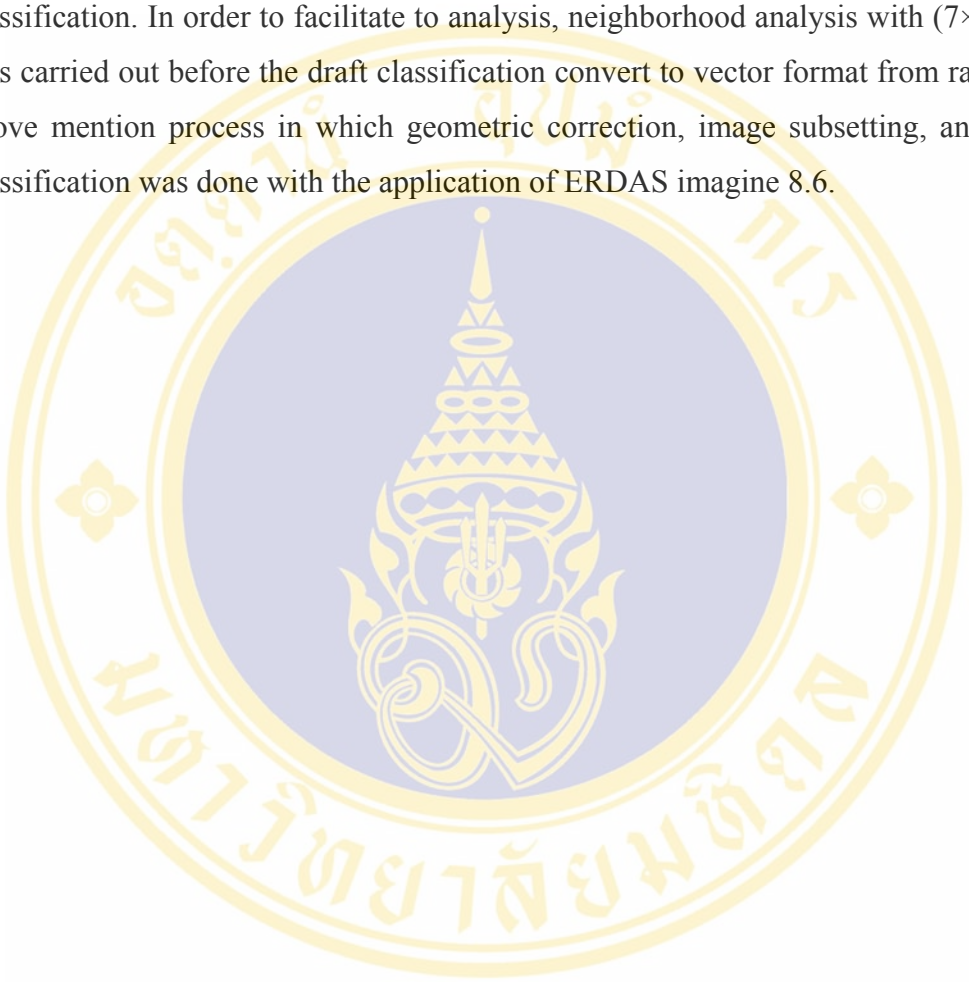
for each class depends on the classified class of previous classification information. For each land use class any number of polygon were added in their signature value. The average value was calculated from the selected polygons for each class. As next step of land use classification, the image was classified under the supervised classification. In order to facilitate to analysis, neighborhood analysis with (7×7) pixel was carried out before the draft classification convert to vector format from raster. All above mention process in which geometric correction, image subsetting, and image classification was done with the application of ERDAS imagine 8.6.



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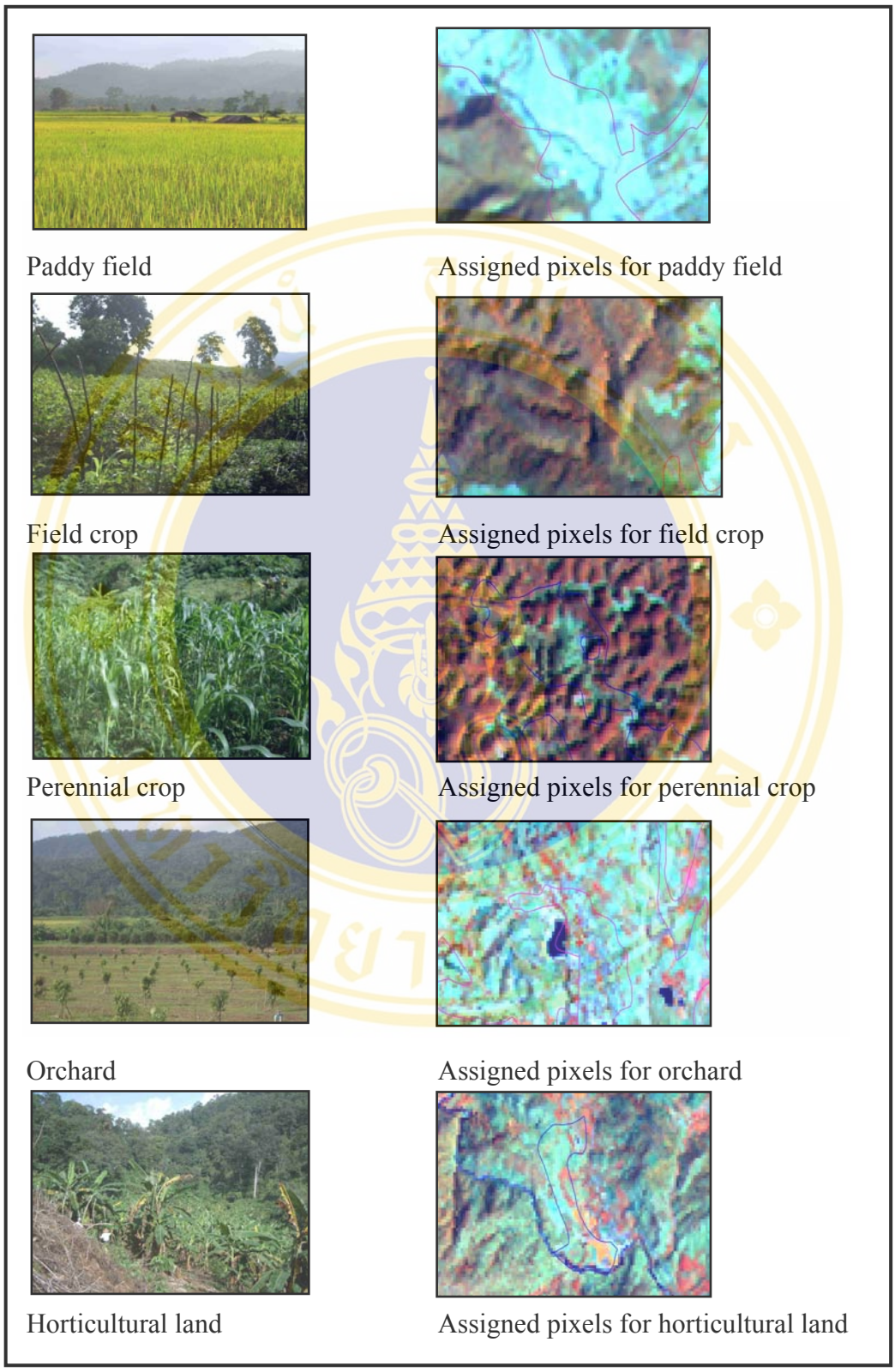

Figure 3.2: Land use types from satellite image and ground conditions

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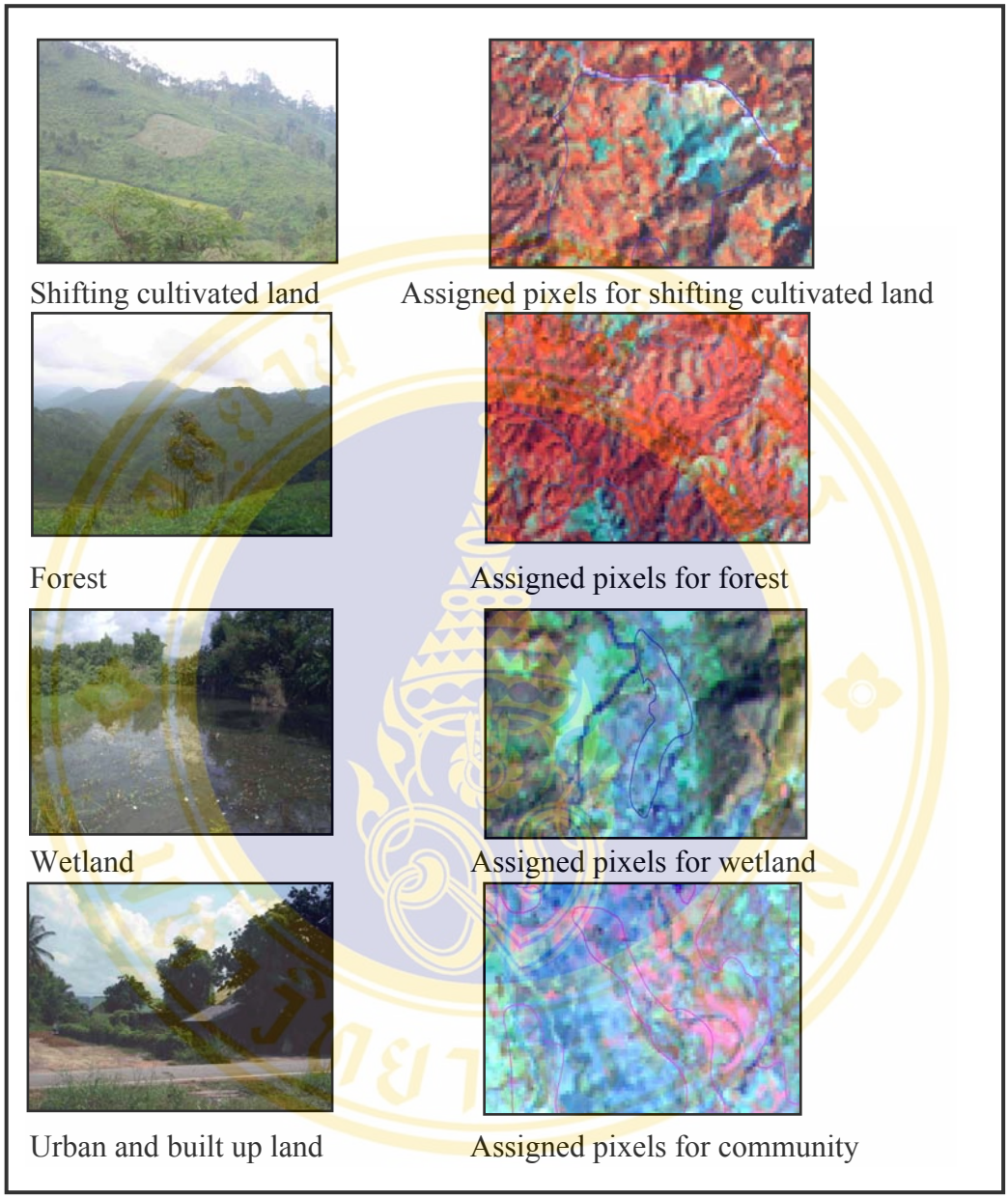

Figure 3.2: (Cont.)

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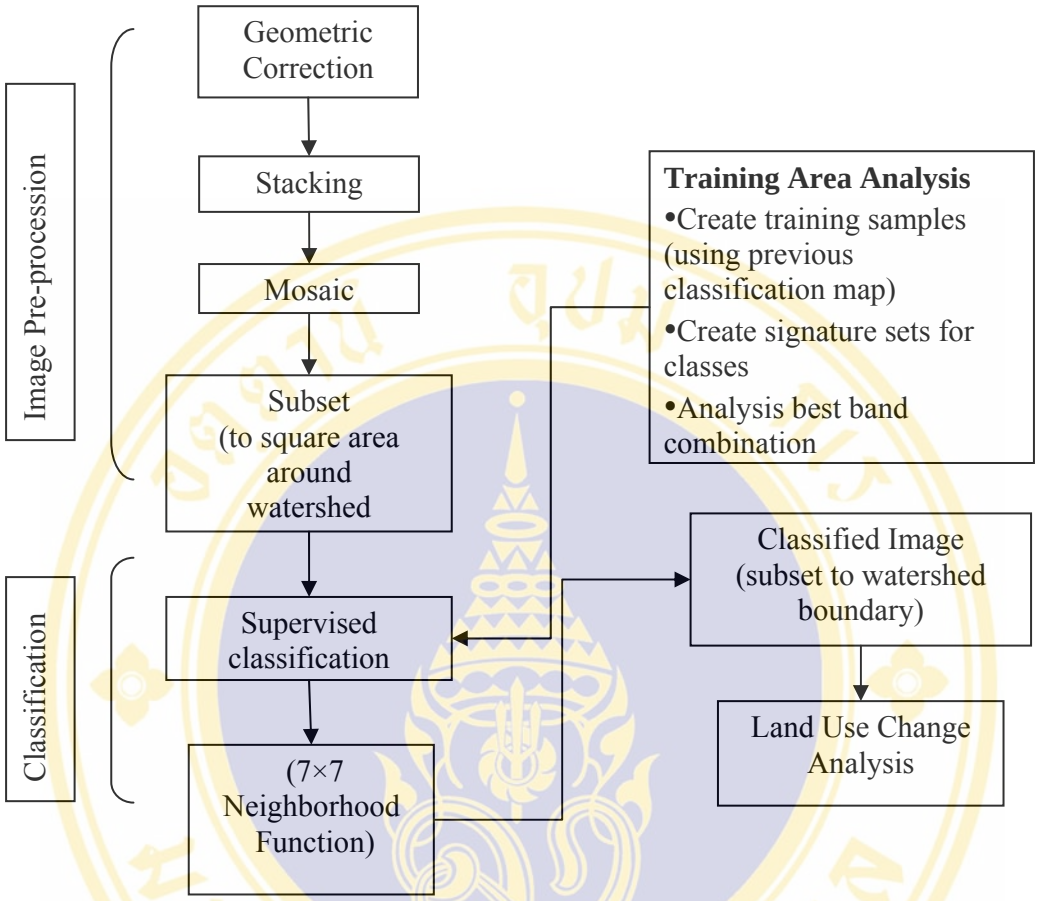

Figure 3.3: Image pre-processing and classification methodology flow diagram

3.4.3.3 Land use map processing and land use analysis

In this study, the land use description was separated into 4 parts from 1989 to 2004. After ground verification process, the land use map was adjusted and corrected before the complete map was produced. Land use change detection is necessary for updating land cover maps. The change was usually detected by comparison between four multi date images. The method of change detection is divided into three;

a) comparison between three land cover maps which are independently produced

b) change enhancement by integrating three images into a color composite or principal component image

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The draft classification vector image required polygon dissolve process which same class polygons were defined as same group. From 1989 to 2004 year period, four periods were divided in order to analysis land use. Percentage of each land use for each period was calculated after existing land use classes has been identified. In this study, land use change throughout from 1989 to 2004 within each land use class as well as same land use in different period was analyzed by using ARCGIS version 9.1.

3.4.4 The analysis of land use change effect to runoff

The analysis of land use changes within each land use type had been carried out based on land use/cover situation in each study period. Overlaying of each land use map is an effective way to analyze the changes from one land use type to other by intersecting two maps of land cover from different periods. After recognizing the area of land use changes within each land use types, land use change matrix was applied to describe land use change within each land use type during a certain period. In order to find out the relationship between changes from each land use type to others and runoff-rainfall ratio, regression analysis had been used in this analysis. In this analysis, the relationship was studied between land use changes during each period 1989-1995, 1995-2000, and 2000-2004 and runoff-rainfall ratios in 1995, 2000, and 2004.

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CHAPTER 4
RESULTS AND DISCUSSION

The aim of this chapter is to describe the results and discuss about the quantitative data of rainfall, runoff, and land use changes in each study period and analysis of relationship between each land use change and runoff-rainfall ratio.

4.1 Output of rainfall analysis

The result was described in detail to analyze annual distribution of rainfall in study area using Thiessen method in each study period.

4.1.1 The analysis of rainfall data using Thiessen method

There were four stations to calculate the annual rainfall in the study area. It can be shown that the area of each station polygon of the whole study area was expressed as a percentage. Table 4.1 explained that annual rainfall 1532.71 mm was estimated by adding up weighted rainfall from each station for the 1995 year.

Table 4.1: Annual rainfall using the Thiessen polygon method in 1995

Name of station	Polygon area (km^2)	Weight %	Rainfall (mm)	Weighted rainfall (mm)
Wiang Haeng	502.26	0.26	1398.8	363.69
Mae Taeng	318.94	0.16	1561.8	249.89
Doi Chiang Dao Watershed Research	1331.50	0.22	1678	369.16
Fang	1106.90	0.36	1527.7	549.97
Total	1954.21	1		1532.71

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The annual rainfall from Wiang Haeng, Mae Taeng, Doi Chiang Dao, and Fang rain gage station was estimated for Mae Taeng watershed. It was revealed that annual rainfall was within a range from 1000 mm to 1600 mm by using Thiessen method in each study period in table 4.2.

Table 4.2: Rainfall accepted by four rain gage stations and annual rainfall using the Thiessen polygon method in Mae Taeng Watershed

Year	Station Name				Annual rainfall
	Wiang Haeng	Mae Taeng	Doi Chiang Dao Watershed Research	Fang	
1989	906.82	980.80	1331.50	1106.90	1084.1
1995	1398.8	1561.8	1678	1527.7	1532.7
2000	1204.34	863.6	1432.6	1260.6	1302.0
2004	1122.6	1078.78	1741.4	1707.4	1462.0

4.2 Output of runoff analysis

As the runoff data collected from the Royal irrigation Department was volume of annual runoff, it was converted to annual runoff (mm) by dividing area of the study area (1902) km^2. Table 4.3 revealed that annual runoff of study period of Mae Taeng river.

Table 4.3: Annual runoff of four periods in Mae Taeng River

Year	Annual runoff (MCM)	Annual runoff(mm)
1989	343.34	181.10
1995	623.8	327.97
2000	389.05	204.54
2004	534.04	280.78

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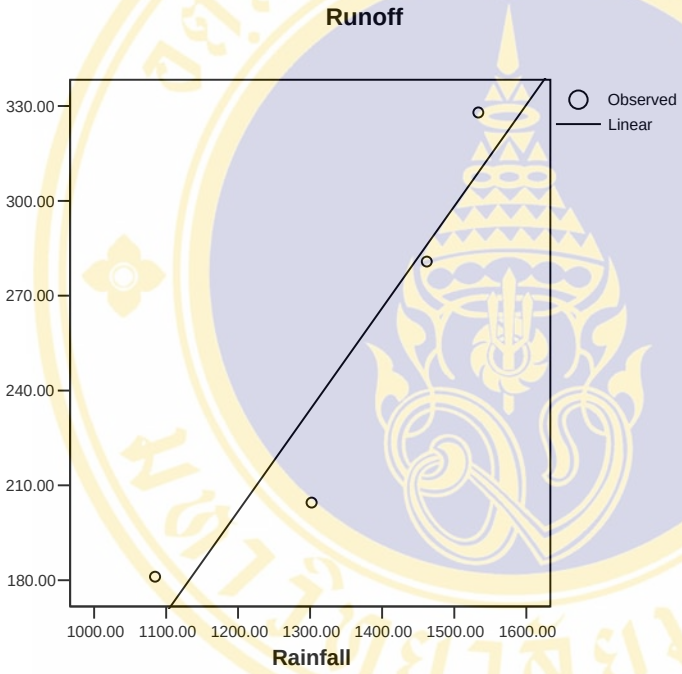
4.3 Runoff-rainfall relationship

Based on land use change assessment year, how relationship between those land use changes and rainfall and runoff was analyzed for the study. It was based on the time periods which are used in land use change assessment. It was recognized that the correlation between rainfall and runoff was correlated each other as the result revealed that correlation is significant at 0.05 level (1-tailed) (Figure 4.1).



In order to analysis relationship between land use change and runoff, runoff-rainfall ratio was calculated based on rainfall and runoff data in study period in table 4.4.

Figure 4.1: Correlation between rainfall and runoff in Mae Taeng watershed

Table 4.4: Runoff-rainfall ratio for 1995, 2000, and 2004

	1995	**2000**	**2004**
Runoff (mm)	327.97	204.54	280.78
Rainfall (mm)	1533.4	1302.0	1462.0
Runoff-Rainfall Ratio	0.2113	0.1571	0.1927

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4.4 Land use and land cover proportions

According to land use classification system in Thailand, component of land use are mostly composed of forest, shifting cultivation, horticulture, orchard, perennial crop, field crop and paddy field, wetland and community and built up land. There was a disproportionate distribution of nine land use types in the study region. Paddy field, field crop, perennial crop, horticulture and shifting cultivated land had small proportion and orchard, forest had large proportion.

1) Land use map, 1989

The classification of the 1989 image showed that dominant class of Mae Taeng watershed was forest 42% and paddy field class 5%, field crop 12, orchard 24%, horticulture 3%, shifting cultivation 13%, wetland and community 1% respectively (figure 4.2).

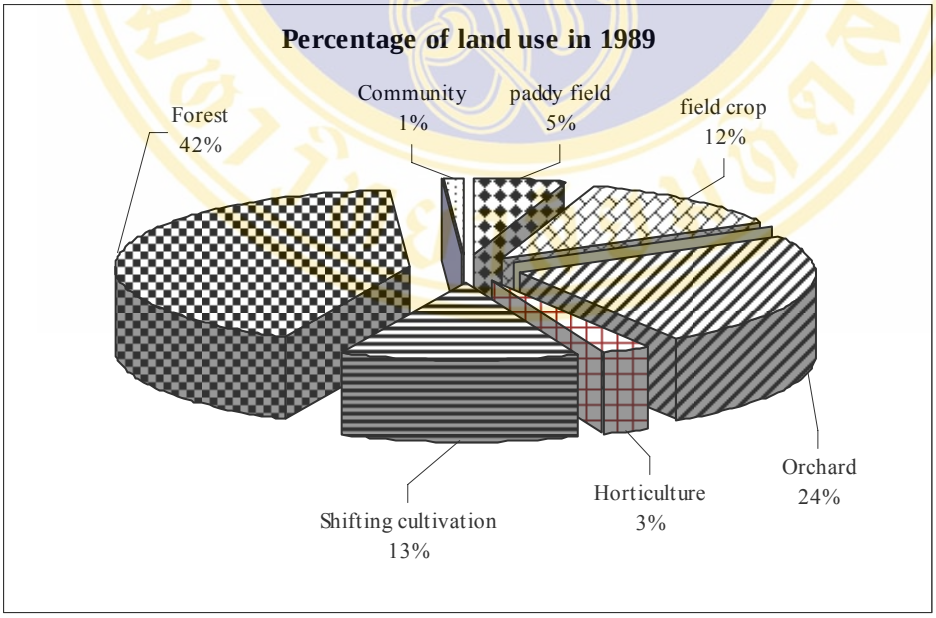

Figure 4.2: Percentage of land use in 1989

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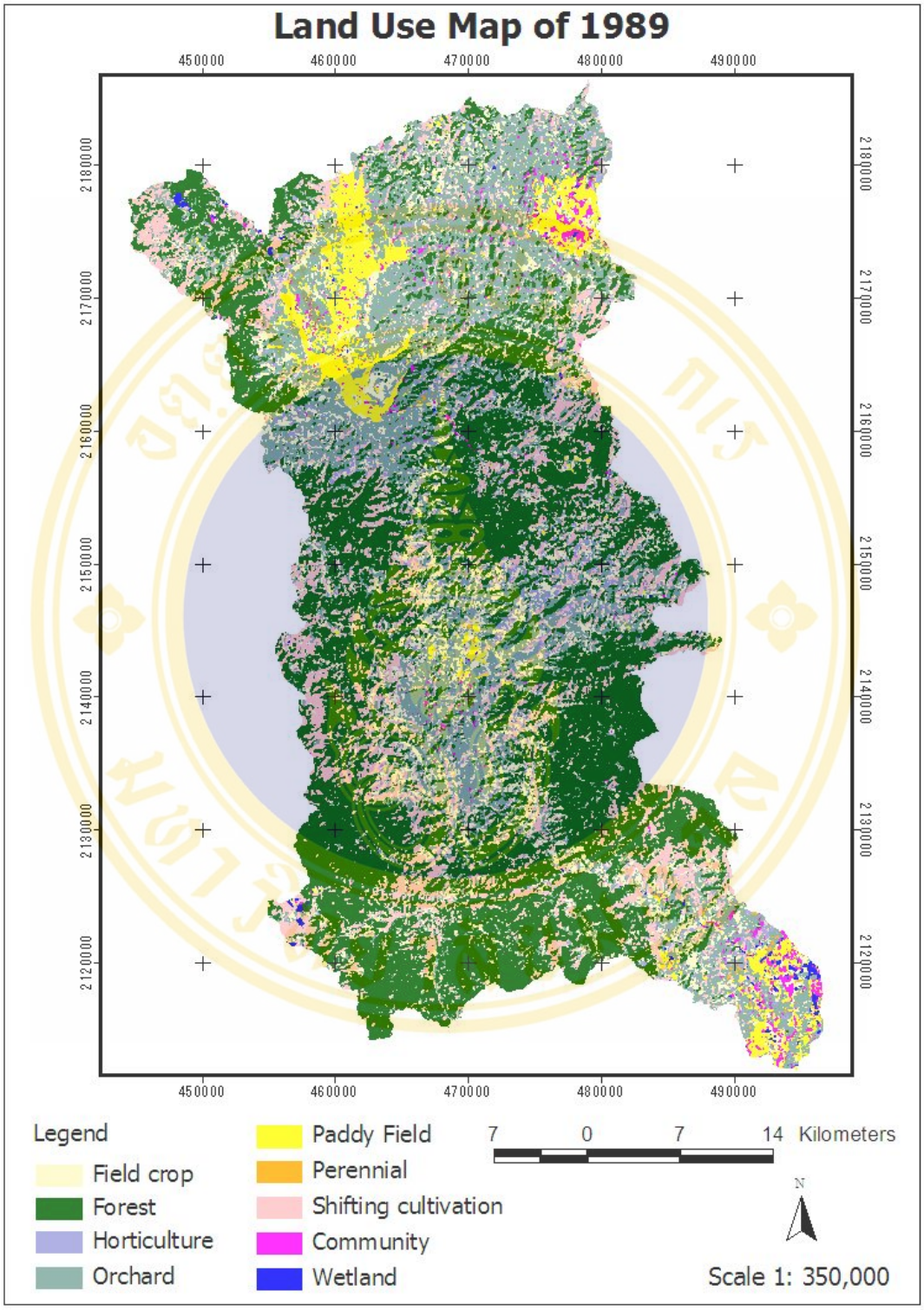

Figure 4.3: Land use map of Mae Taeng watershed, 1989

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2) Land use map, 1995

In 1995, the land cover was still dominated forest 45% and followed by field crop 16%, shifting cultivation 11%, orchard 10%, perennial crop 8%, horticulture 6%, paddy field3%, and community 1 % in figure 4.4.

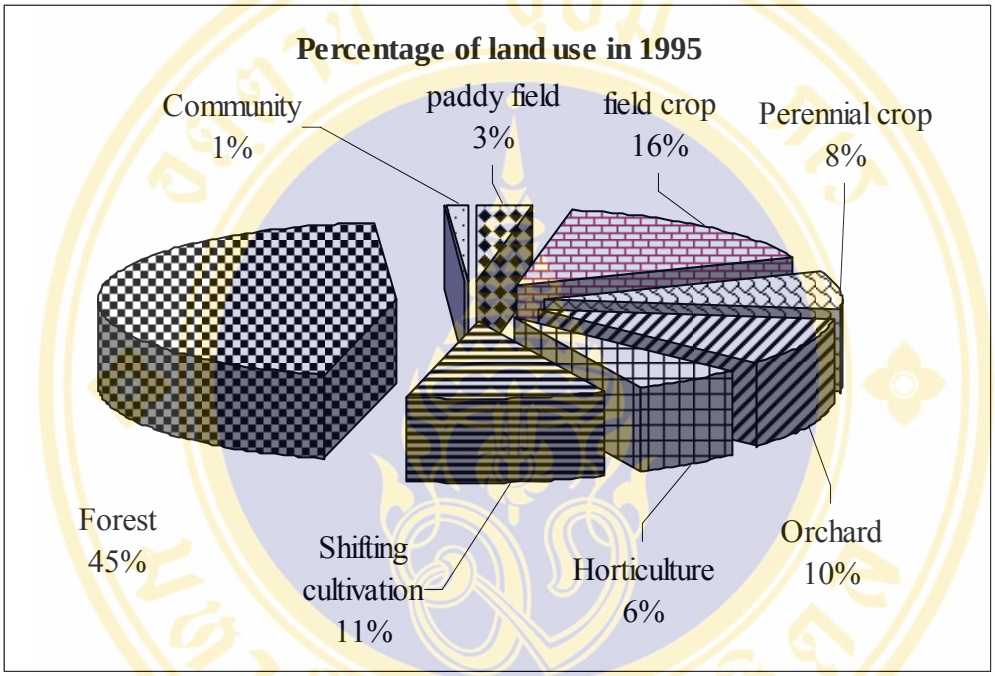

Figure 4.4: Percentage of land use in 1995

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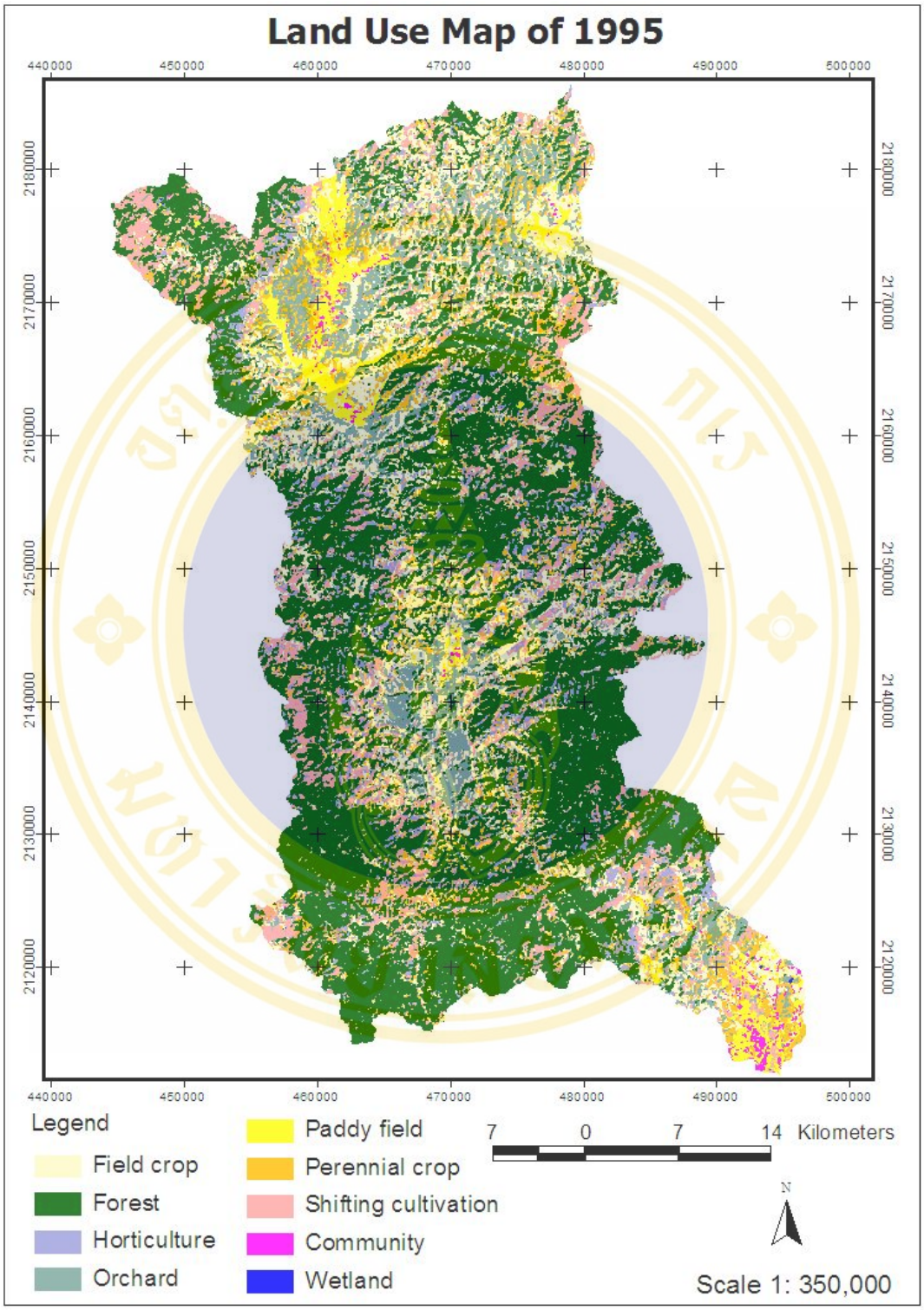

Figure 4.5: Land use map of Mae Taeng watershed, 1995

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3) Land use map, 2000

In 2000, the orchard 48 % replaced the dominant land cover and forest remained 36% of land cover and followed by shifting cultivation 8%, perennial 3%, wetland 2%, and paddy field, field crop and community occupied 1% of total land area (figure 4.6).

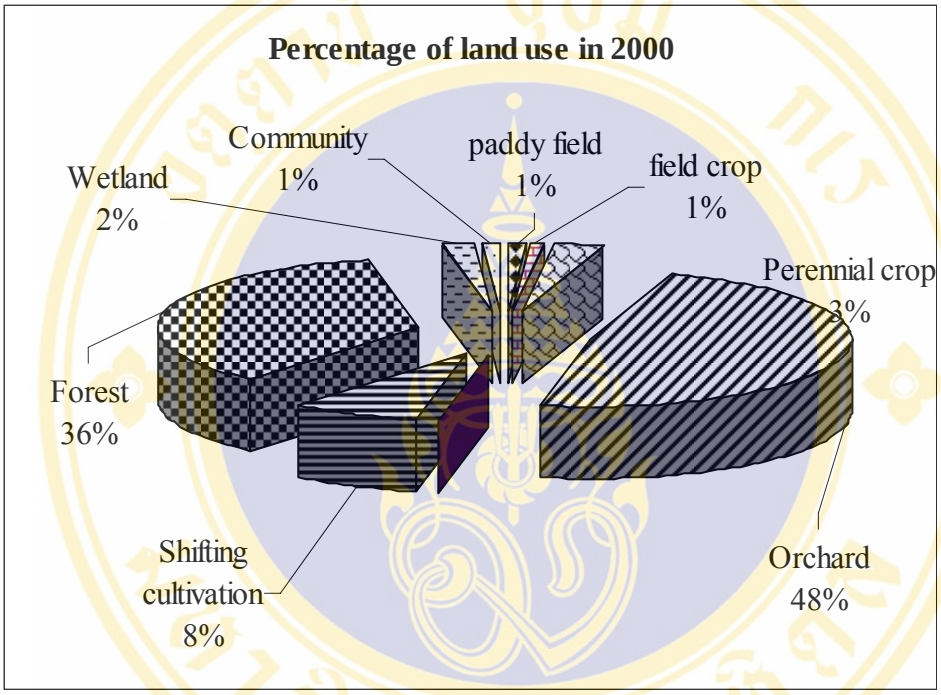

Figure 4.6 Percentage of land use in 2000

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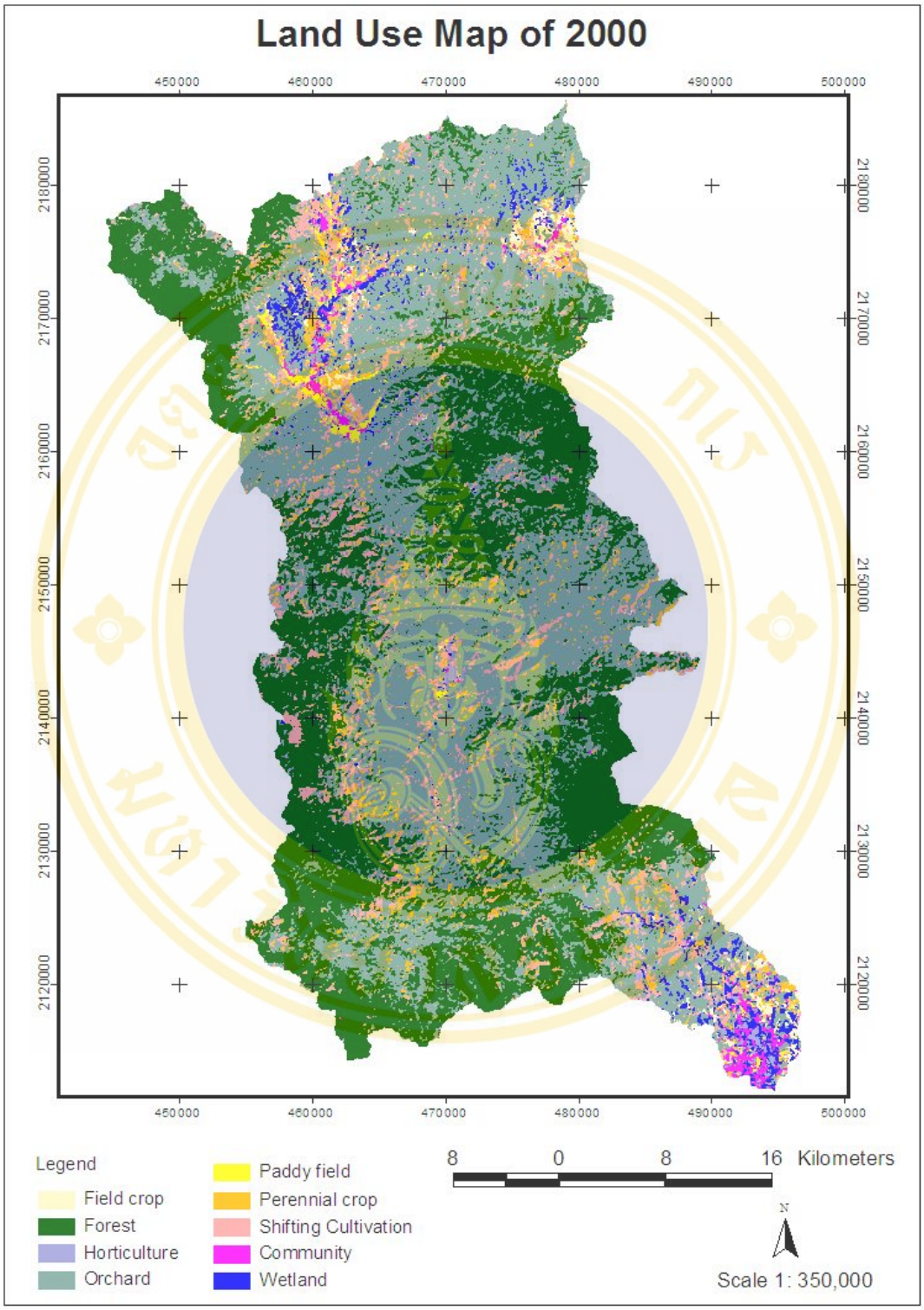

Figure 4.7: Land use map of Mae Taeng watershed, 2000

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4) Land use map, 2004

In 2004, area of orchard and field crop was 27% and 26% after forest regained the dominant land use with 34%, above shifting cultivation 8%, paddy field 4%, and perennial crop 1% (figure 4.8).

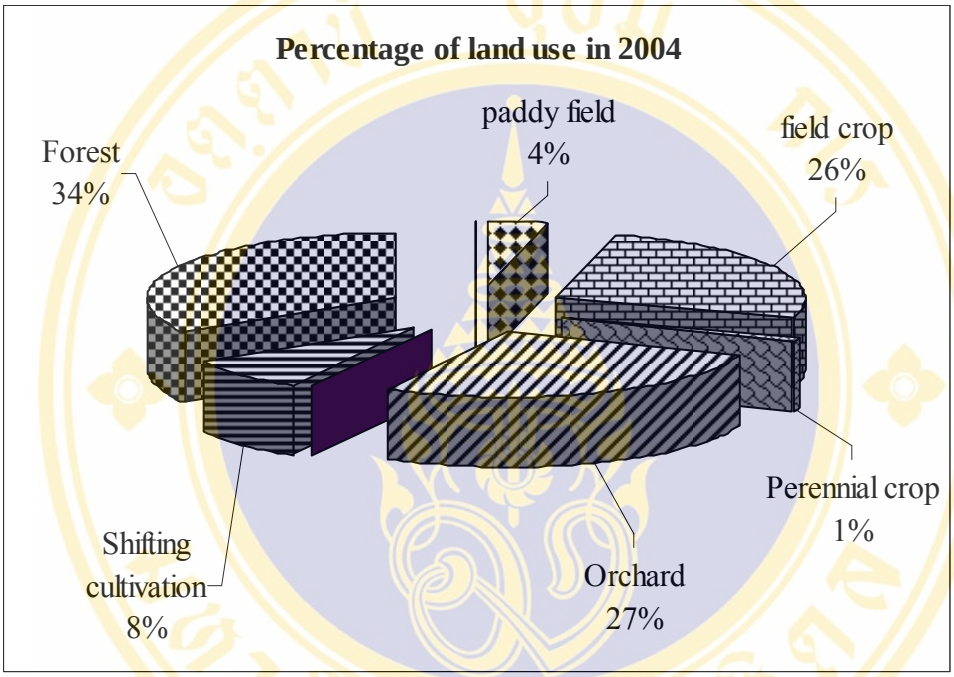

Figure 4.8 Percentage of land use in 2004

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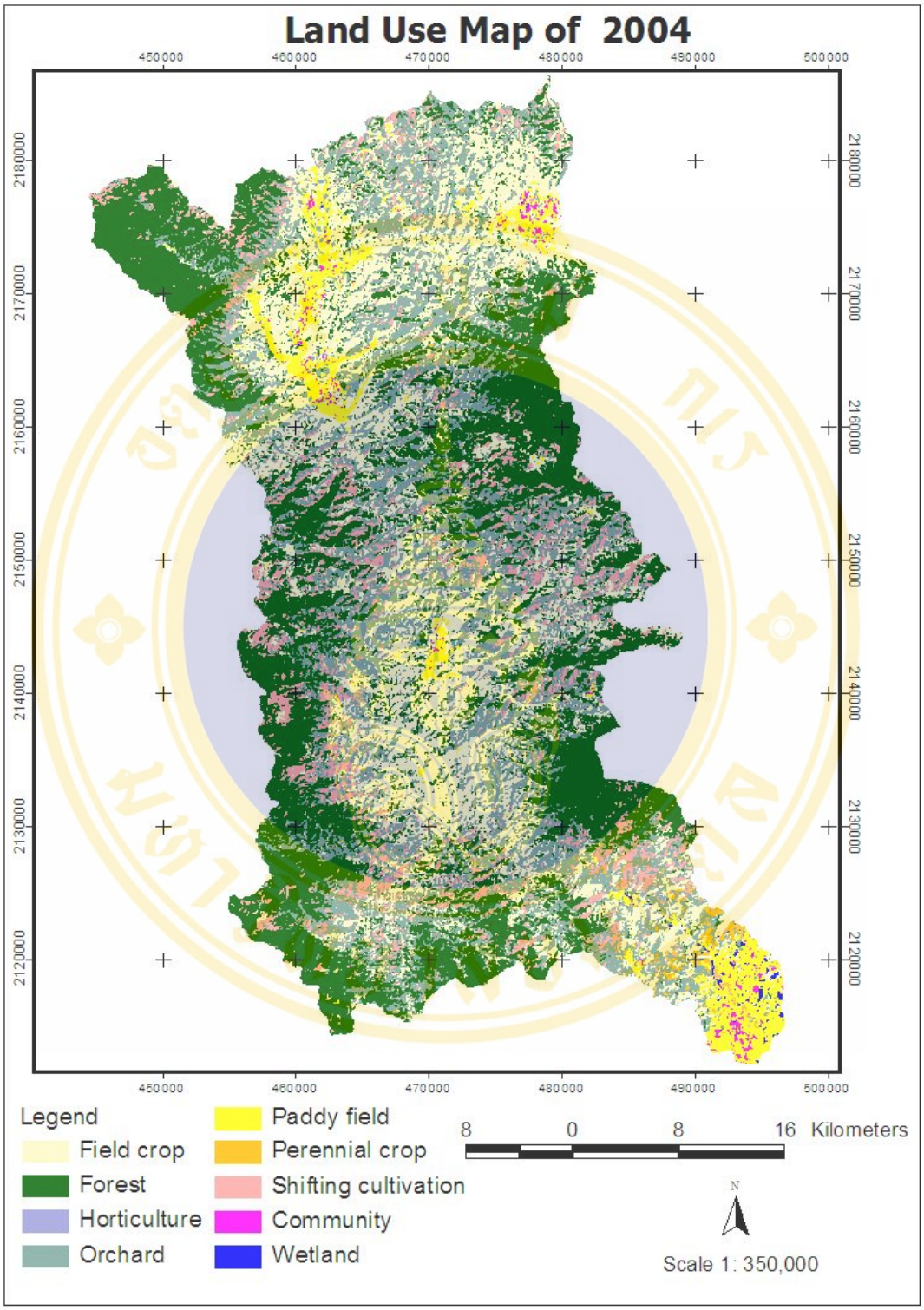

Figure 4.9: Land use map of Mae Taeng watershed, 2004

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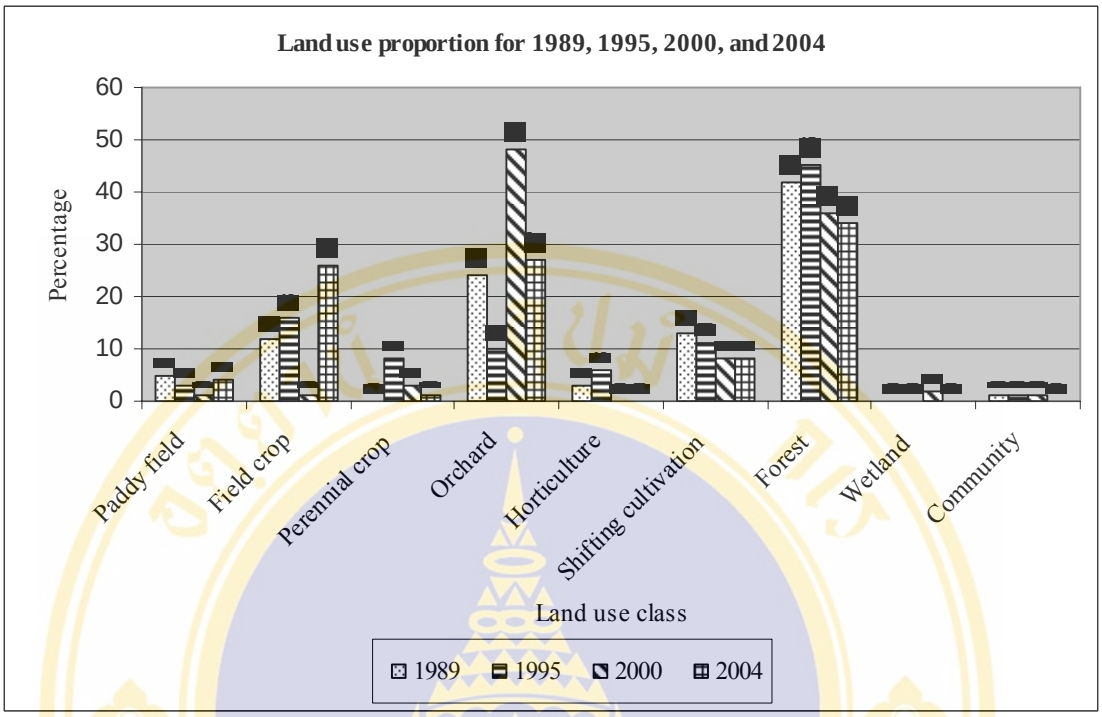

(Percentage = amount of each land use as proportion of total land use land cover area for that year)

Figure 4.10: Land use/cover proportion in 1989, 1995, 2000, and 2004 years

Figure (4.10) explained that the percentage of each land use was compared with each period of land use assessment periods. It was noticed that most of uneven changes had been occurred in field crop and orchard land use types. The percentage of shifting cultivated land and perennial crop land use types were slightly decreased in each study period.

4.5 Land use change trends

Figure (4.11) showed that, there was a steady decline in forest area through the study period from 1989 to 2004. There was a decline in paddy field from the period 1989-2000, but it was raised after 2000 year. The aggregate change for paddy field from 1989 to 2004 was 48%. The aggregate increase for field crop was 28% from1989-2004, but only rapidly decreases in the period 1995-2000. Field crop class was increased 25% and 96% in 1989-1995 and 2000-2004 after declined from 1995-2000. The aggregation for that class was 28% throughout 1989 to 2004. There was initial

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increase 100% from 1989 to 1995 in perennial crop, steady decline from 1995 to 2004 and aggregate change was 30%. Orchard initial decreased in area 58 from 1989 to 1995 and again in 2000-2005 to 44% after increased 79% within 1995-2000 periods. There was 50% increase in horticulture in initial period and later declined to 100% from 1995 to 2000. Shifting cultivation dramatically decreased in area through the study period 1989-2000 with the aggregate lost of 42%. From 1989 to 1995 forest increased by 7%, and decreased by 20% and 6% from 1995 to 2004. The aggregate change of forest was an increase of 19% while the aggregate change for wetland and community were the decrease of 0% and 100% respectively.

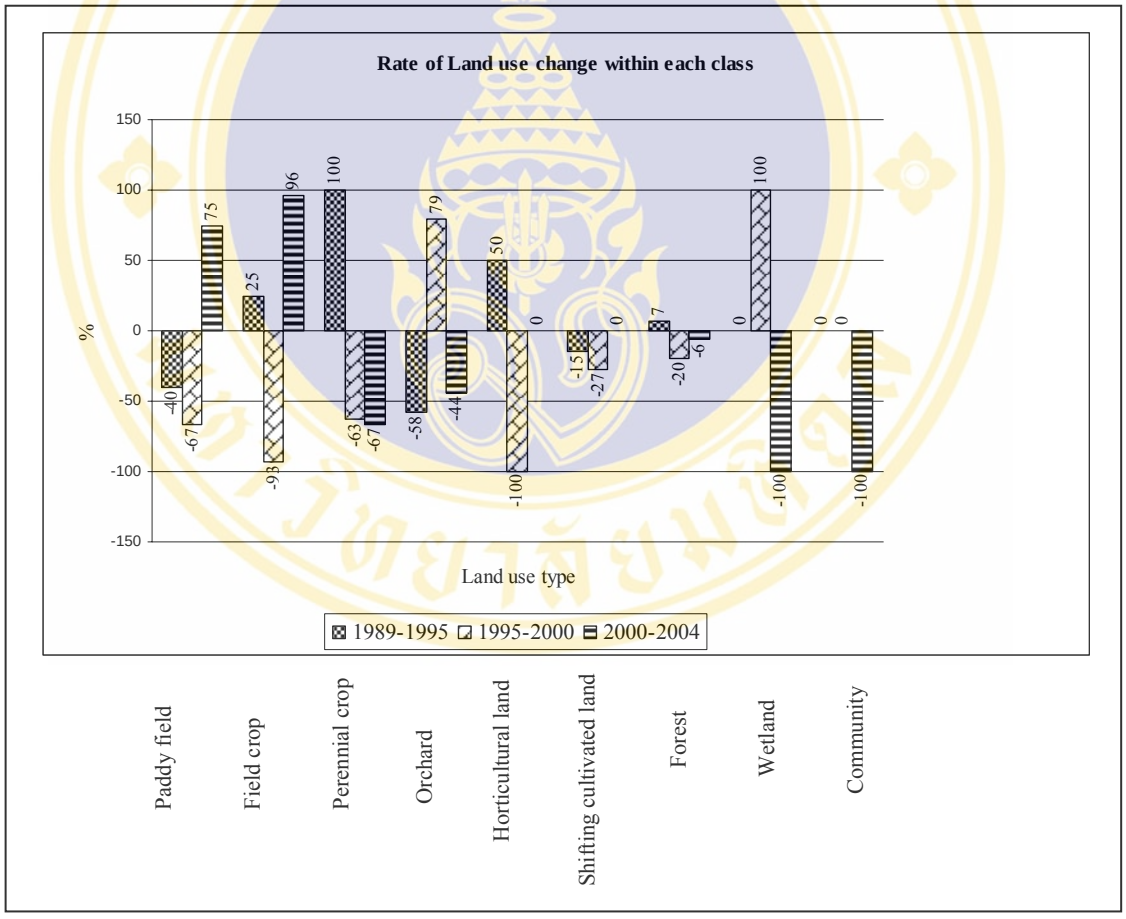

Figure 4.11: Rate of land use change within each class in 1989-1995, 1995-2000, 2000-2004 period

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4.6. Land use change

There are nine types of land use in the study area. The study of land use change was analyzed within the period of 1989 to 2004. The periods were divided into three portions. Table 4.5 showed that land use changes from one land use type to other in term of area (km^2) during 1989-1995.

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Table 4.5: Land use area changes in Mae Taeng watershed from 1989 to 1995

unit=km^2

Period	Paddy field (A1)	Field crop (A2)	Perennial (A3)	Orchard (A4)	Horti-cultural land(A5)	Shifting cultivated land (A6)	Forest (F)	Wetland (M)	Comm-unity (U)
Paddy field (A1)	*	1.65	0.19	4.07	0.71	1.57	0.23	1.65	3.34
Field crop (A2)	18.70	*	0.84	146.53	9.03	14.52	8.42	1.85	8.04
Perennial (A3)	8.76	49.67	*	67.71	7.59	3.61	6.29	0.60	0.89
Orchard (A4)	0.01	10.18	0.02	*	27.55	56.24	18.54	0.02	0.04
Horticultural land(A5)	5.33	30.31	0.02	140.72	*	0.98	1.35	1.80	6.99
Shifting cultivated land (A6)	1.22	5.49	0.05	16.00	14.34	*	2.64	0.16	0.39
Forest (F)	0.21	20.99	0.00	75.54	0.91	16.28	*	0.66	2.96

- Land use changes within same land use type

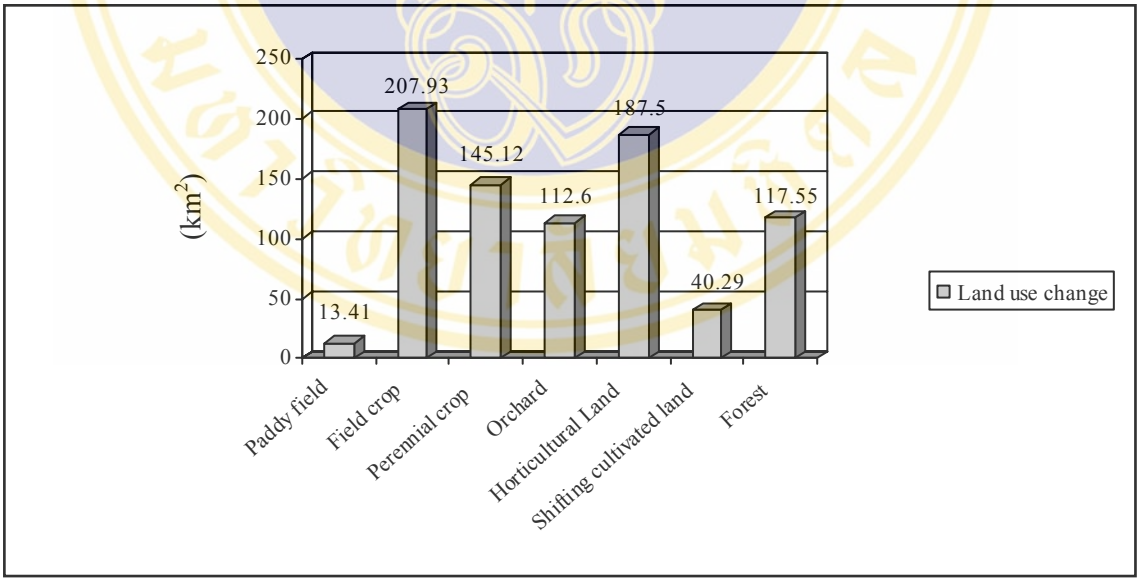

Figure 4.12: Each type of land use changes in Mae Taeng watershed during 1989-1995

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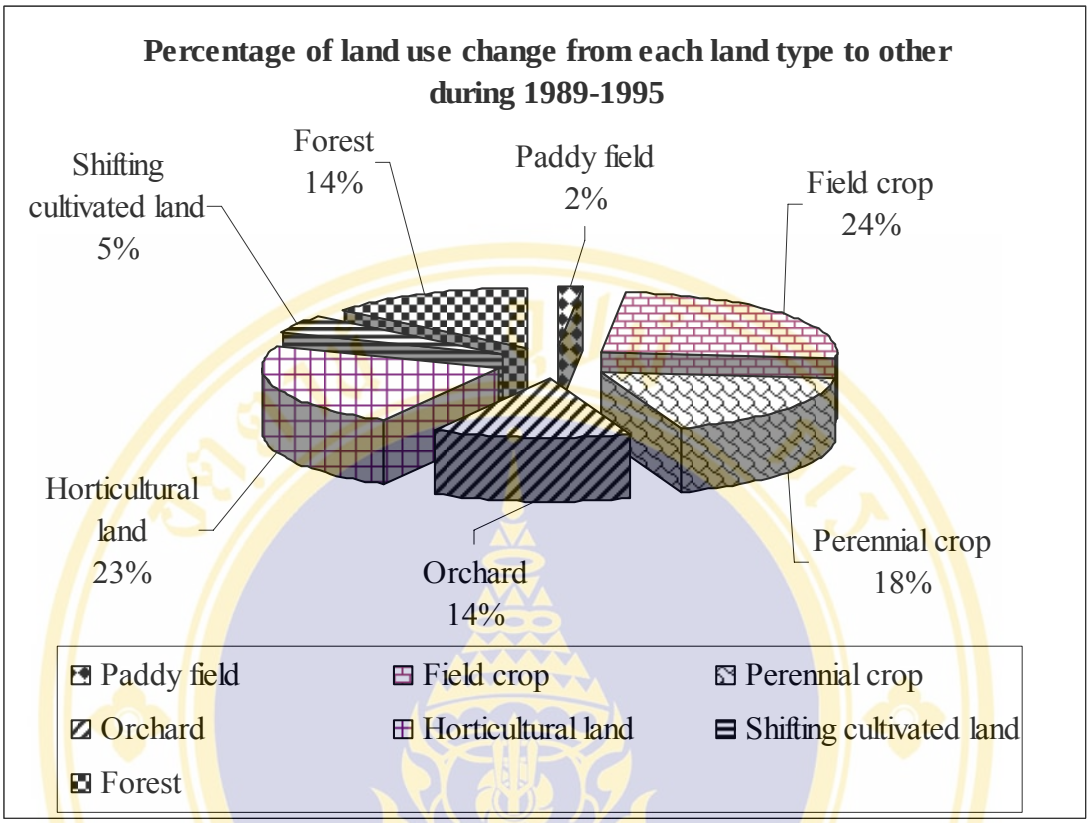

Figure 4.13: Percentage of land use change from each land use type during 1989-1995

Figure 4.12 showed that during 1989-1995 there were 824.4 km^2 land use changes together, of which field crop, horticultural land, perennial crop, forest, orchard, shifting cultivated land, and paddy field area changes accounted for 207.93 km^2, 187.5 km^2, 145.12 km^2, 117.55 km^2, 112.6 km^2, 49.29 km^2, and 13.41 km^2 respectively. In figure (4.13), of the percentage of land use changes from each land use type, the changes from field crop to other land use classes was the highest during 1989-1995. The paddy field to other land use changes was the least percentage among others.

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Table (4.6) showed that area of land use change from each land use type to others during in Mae Taeng watershed the period 1995-2000.

Table 4.6: Land use area changes in Mae Taeng watershed from 1995 to 2000

unit=km^2

Period	Paddy field (A1)	Field crop (A2)	Perennial (A3)	Orchard (A4)	Horti-cultural land(A5)	Shifting cultivated land (A6)	Forest (F)	Wetland (M)	Comm-unity (U)
Paddy field (A1)	*	2.46	5.33	10.91	3.32	15.03	10.91	6.79	10.9
Field crop (A2)	1.00	*	13.46	233.02	0.20	37.02	18.88	3.52	1.65
Perennial (A3)	0.98	3.21	*	104.35	0.39	9.04	16.05	6.54	1.87
Orchard (A4)	0.03	0.12	11.22	*	0.53	23.98	23.39	0.78	0.14
Horticultural land(A5)	0.28	3.60	1.98	152.41	*	8.24	3.51	17.28	0.45
Shifting cultivated land (A6)	0.98	0.93	25.41	75.55	2.21	*	45.05	2.23	0.50
Forest (F)	0.04	0.11	2.57	278.58	0.26	10.41	*	4.38	0.03

* Land use changes within same land use type

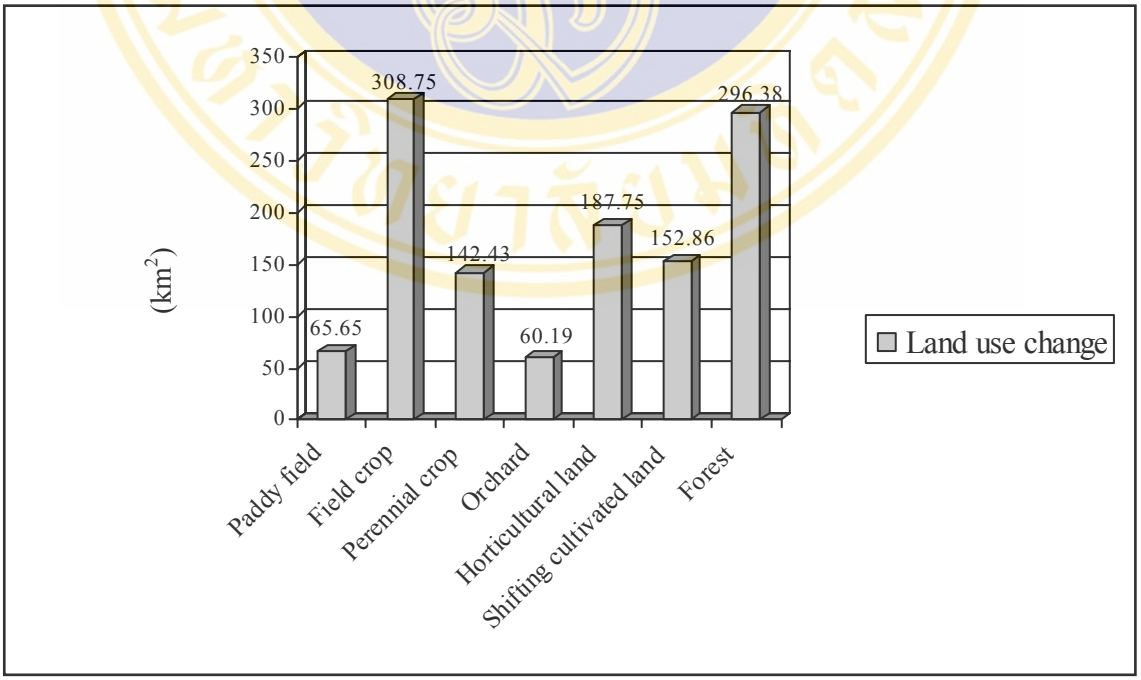

Figure 4.14: Each type of land use changes in Mae Taeng watershed during 1995-2000

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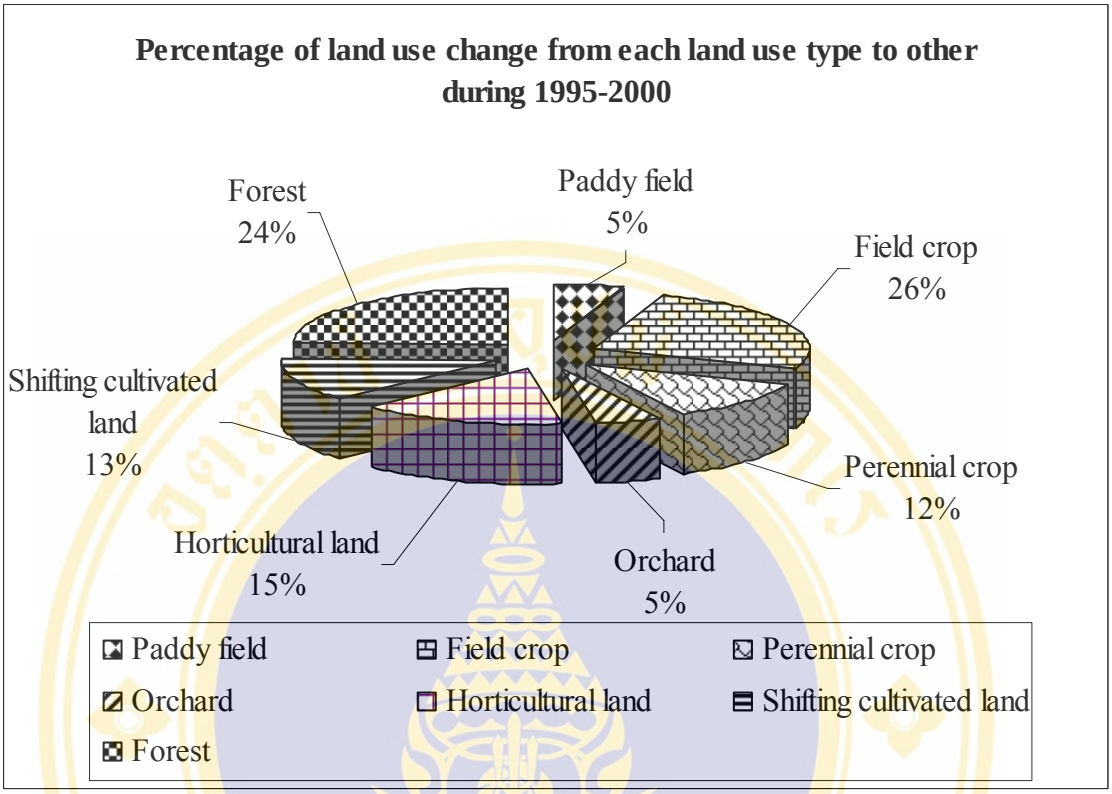

Figure 4.15: Percentage of land use changes from each land use type during 1995-2000

Figure 4.14 showed that during 1995-2000 there were 1214.01 km^2 land use changes together, of which field crop, forest, horticultural land, shifting cultivated land, perennial crop, paddy field, and orchard area changes accounted for 308.75 km^2, 296.38 km^2, 187.75 km^2, 152.86 km^2, 142.43 km^2, 65.65 km^2, and 60.19 km^2 respectively. In figure (4.15), of the percentage of land use changes from each land use type, the changes from field crop to other land use classes was the highest during 1989-1995. The orchard to other land use changes was the least percentage among others.

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Table (4.7) showed that area of land use change from each land use type to others in Mae Taeng watershed during the period 2000-2004.

Table 4.7: Land use area changes in Mae Taeng watershed from 2000-2004

unit=km^2

Period	Paddy field (A1)	Field crop (A2)	Perennial (A3)	Orchard (A4)	Horti-cultural land(A5)	Shifting cultivated land (A6)	Forest (F)	Wetland (M)	Comm-unity (U)
Paddy field (A1)	*	4.40	0.22	2.03	0.01	0.15	0.81	0.07	0.54
Field crop (A2)	7.68	*	0.43	2.55	0.09	0.26	0.90	0.34	1.55
Perennial (A3)	7.22	21.53	*	17.40	0.13	6.57	11.23	0.24	0.85
Orchard (A4)	24.41	329.58	6.19	*	0.20	79.86	170.65	0.91	1.35
Horticultural land(A5)	3.63	1.04	0.25	0.80	*	0.40	1.16	0.11	0.73
Shifting cultivated land (A6)	13.00	48.54	1.60	42.14	0.17	*	37.11	0.44	1.06
Forest (F)	1.29	68.56	1.37	145.75	0.00	57.65	*	0.01	0.17

* Land use changes within same land use type

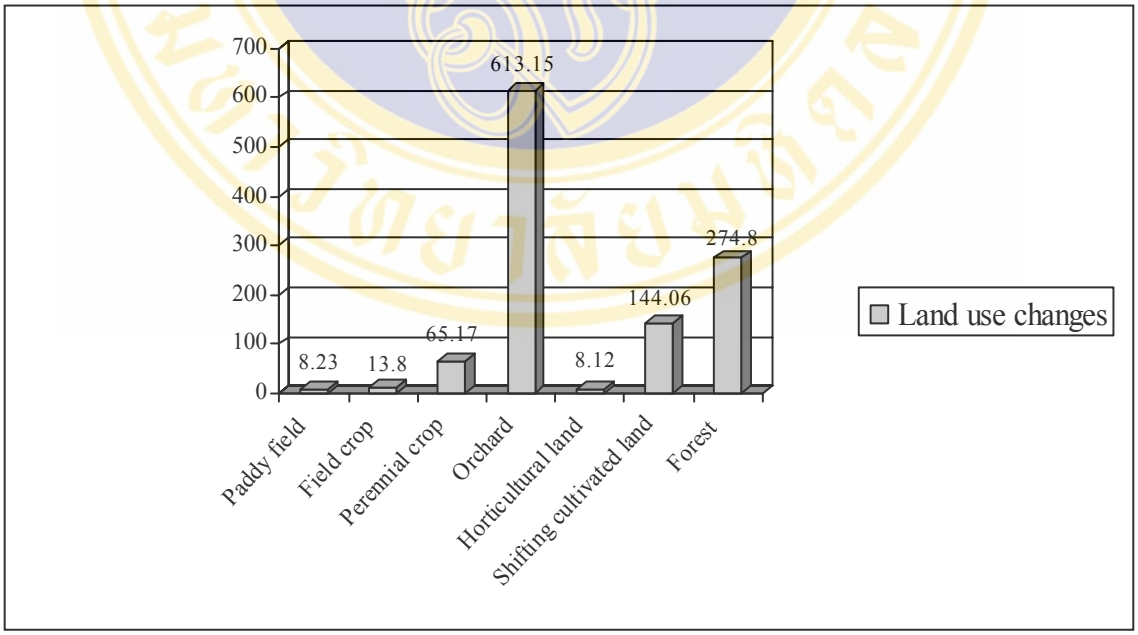

Figure 4.16: Each type of land use change in Mae Taeng watershed during 2000-2004

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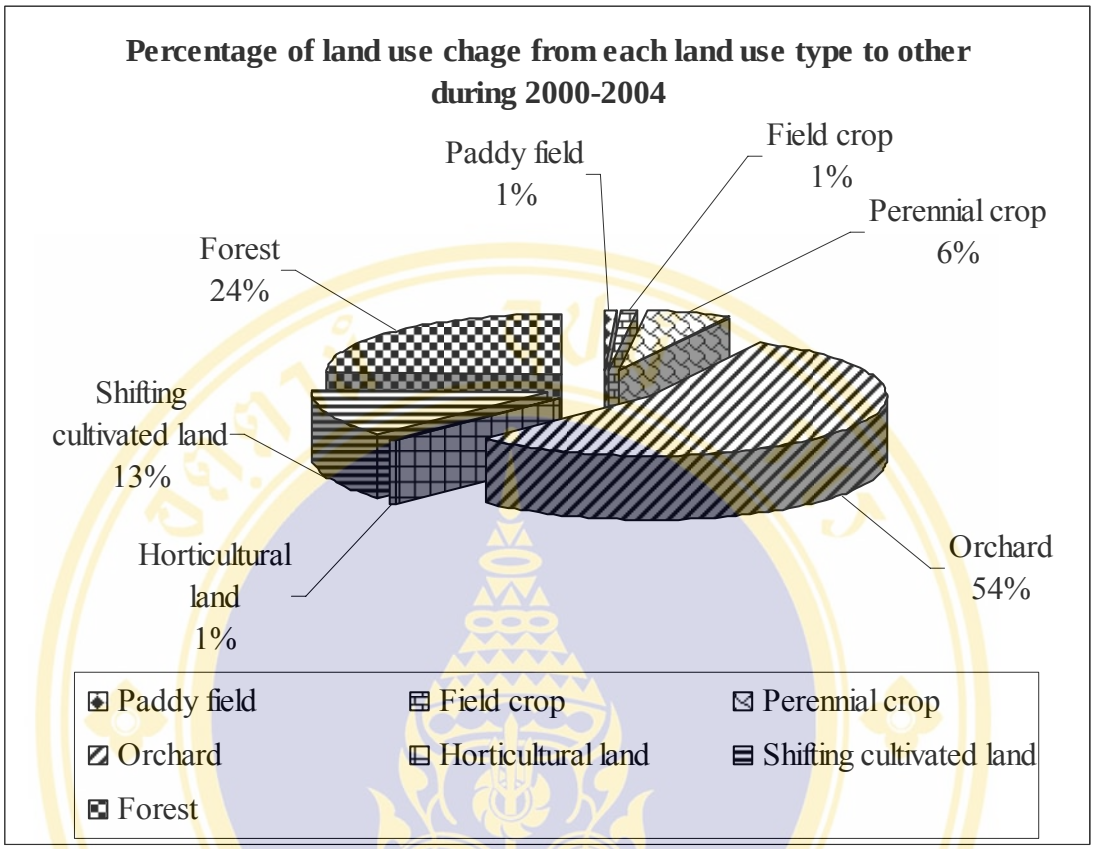

Figure 4.17: Percentage of land use changes from each land use type during 2000-2004

Figure 4.16 showed that during 2000-2004 there were 1127.33 km^2 land use changes together, of which orchard, forest, shifting cultivated land, perennial crop, field crop, paddy field, horticultural land changes accounted for 613.15 km^2, 274.8 km^2, 144.06 km^2, 65.17 km^2, 13.8 km^2, 8.23 km^2, and 8.12 km^2 respectively. In figure (4.17), of the percentage of land use changes from each land use type, the changes from orchard to other land use classes was the highest on during 1989-1995. The horticultural land to other land use changes was the least percentage among others.

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Table 4.8: Land use changes percentage in Mae Taeng watershed from 1989-1995

Unit=%

Period	Paddy field (A1)	Field crop (A2)	Perennial (A3)	Orchard (A4)	Horti-cultural land(A5)	Shifting cultivated land (A6)	Forest (F)	Wetland (M)	Comm-unity (U)
Paddy field (A1)	*	0.07	0.01	0.21	0.04	0.08	0.01	0.08	0.17
Field crop (A2)	0.96	*	0.04	7.50	0.46	0.74	0.43	0.09	0.41
Perennial (A3)	0.45	2.54	*	3.46	0.39	0.18	0.32	0.03	0.05
Orchard (A4)	0.00	0.52	0.00	*	1.41	2.88	0.95	0.00	0.00
Horticultural land(A5)	0.27	1.55	0.00	7.20	*	0.05	0.07	0.09	0.36
Shifting cultivated land (A6)	0.06	0.28	0.00	0.82	0.73	*	0.14	0.01	0.02
Forest (F)	0.01	1.07	0.00	3.87	0.05	0.83	*	0.03	0.15

*Land use changes within same land use type

From 1989 to 1995, area of paddy field to other land use was not much change except 0.21% of paddy field to orchard. The largest conversion from field crop to orchard was 7.5%, while the smallest was field crop to perennial. In terms of conversions from perennial crop, there was small conversion from perennial crop to orchard about 3.46%, field crop 2.54%. The conversion of orchard was to shifting cultivation 2.88% among the conversions to other land use class. Horticultural land use converted 7.2% to orchard though 1.41% of orchard converted to horticultural use in the same period. Shifting cultivated land to other land use class was a little compared to other periods 1995-2000 and 2000-2004. In that period, forest land converted to orchard nearly 3.87% while 1.07% to field crop. There was not much conversion of wetland to other land use classes throughout the study period 1989-1995. Community to other land use was still in small scale compared to conversion within each land use classes through the study period.

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Table 4.9: Land use changes percentage in Mae Taeng watershed from 1995-2000

Unit=%

Period	Paddy field (A1)	Field crop (A2)	Perennial (A3)	Orchard (A4)	Horti-cultural land(A5)	Shifting cultivated land (A6)	Forest (F)	Wetland (M)	Comm-unity (U)
Paddy field (A1)	*	0.13	0.27	0.56	0.17	0.77	0.03	0.35	0.56
Field crop (A2)	0.05	*	0.69	11.92	0.01	1.89	0.97	0.18	0.08
Perennial (A3)	0.05	0.16	*	5.34	0.02	0.46	0.82	0.33	0.10
Orchard (A4)	0.05	0.01	0.57	*	0.03	1.23	1.20	0.04	0.01
Horticultural land(A5)	0.01	0.18	0.10	7.80	*	0.42	0.18	0.88	0.02
Shifting cultivated land (A6)	0.05	0.05	1.30	3.87	0.11	*	2.31	0.11	0.33
Forest (F)	0.00	0.01	0.13	14.26	0.01	0.53	*	0.22	0.00

*Land use changes within same land use type

From 1995 to 2000, the conversion of paddy field to shifting cultivation is more than other changes while the paddy field to orchard, paddy field to community were about 0.56%. In that period, 11.92% of field crop converted to orchard. There was increase conversion of perennial crop to orchard 5.34% than other class of land use. The change from orchard to shifting cultivation was 1.23%. Nearly 7.8% of conversion from horticultural use to orchard was the largest from 1995 to 2000. Nearly 3.87% of shifting cultivated land converted to orchard, 2.31% to forest land. There was 14.26% forest land to orchard with the largest conversion. There was not much conversion of wetland to other land use classes throughout the study period 1995-2000.

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Table 4.10: Land use changes percentage in Mae Taeng watershed from 2000-2004

Unit=%

Period	Paddy field (A1)	Field crop (A2)	Perennial (A3)	Orchard (A4)	Horti-cultural land(A5)	Shifting cultivated land (A6)	Forest (F)	Wetland (M)	Comm-unity (U)
Paddy field (A1)	*	0.23	0.01	0.10	0.00	0.01	0.04	0.00	0.03
Field crop (A2)	0.39	*	0.02	0.13	0.00	0.01	0.05	0.02	0.08
Perennial (A3)	0.37	1.10	*	0.89	0.00	0.34	0.57	0.01	0.04
Orchard (A4)	1.25	16.87	0.32	*	0.01	4.09	8.73	0.05	0.07
Horticultural land(A5)	0.19	0.05	0.01	0.04	*	0.02	0.06	0.01	0.04
Shifting cultivated land (A6)	0.67	2.48	0.08	2.16	0.01	*	1.90	0.02	0.05
Forest (F)	0.07	3.51	0.07	7.46	0.00	2.95	*	0.00	0.01

*Land use changes within same land use type

Note: A1 = Paddy field A3 = Perennial crop A5 = Horticultural land
A2 = Field crop A4 = Orchard A6 = Shifting cultivated land
F = Forest M2 = Wetland U= Community

From 2000-2004, 0.2% of paddy field to field crop was in high proportion. Among those land use types, conversion of field crop to other class did not change. The conversion from perennial crop was to field crop 1.1%. Orchard class was subject to numerous multi-direction conversions through the period 2000-2004. The conversion 16.87% from orchard to field crop was the largest amount compared to other conversions of orchard to forest 8.73%, and 4.09% to shifting cultivation. The conversions of horticultural use to other land use types were under 1%. Moreover, conversions of shifting cultivated land to field crop and orchard were 2.48% and 2.16% respectively. However, 7.46% of forest land converted orchard followed by nearly 3.51% converting to field crop and almost 2.95% to shifting cultivated land. There was not much conversion of wetland to other land use classes throughout the study period 2000-2004.

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4.6.1 Comparison within changes from each land use type to others

Figure 4.18 showed that comparison within changes of area (km^2) from each land use type to other in three study periods. It was noticed that the changes from orchard to other land use was the highest proportion compared to other land use types.

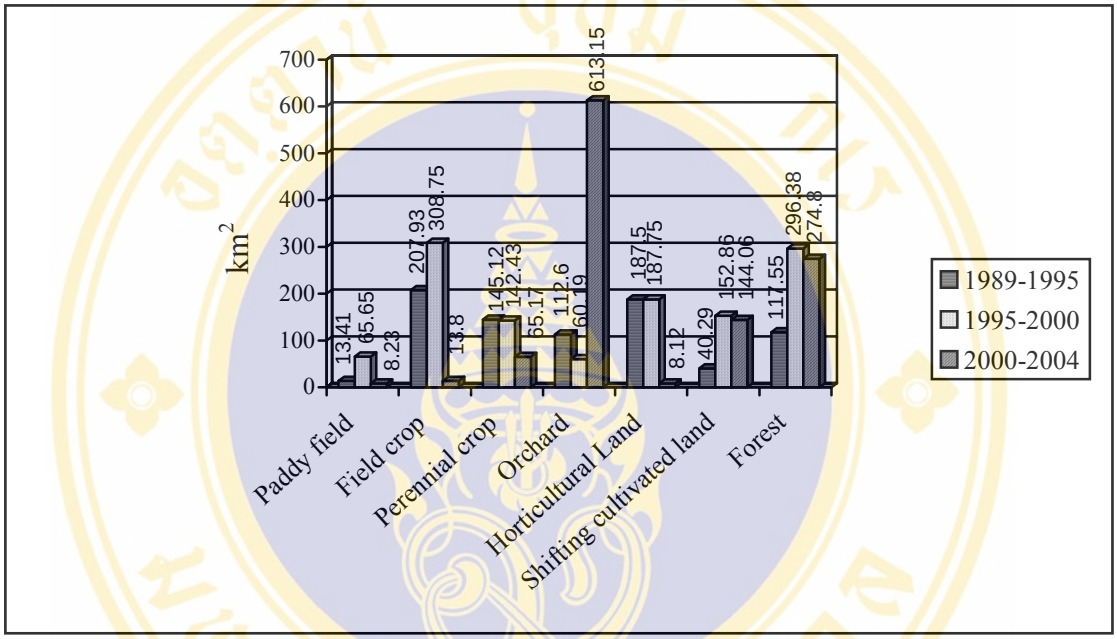

Figure 4.18: Comparison within changes from each land use type to others

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4.7 Relationship between land use changes and runoff-rainfall ratio

There were 81 types of land use changes to analyze the relationship between runoff-rainfall relationship and land use changes within each land use type. Based on land use changes within each land use changes, linear, power, and exponential model were considered. In order to analysis the relationship between land use changes and runoff-rainfall ratio, two variables were used land use changes within each land use class and runoff-rainfall ratio. The results from those model analyses gave different r^2 value, probability, and coefficient of equation for land use change from one type to another. Equations mentioned in table (4.11-4.17) intended to explain runoff-rainfall ratio (y) that depend on percentage land use change within each land use type. However, to apply in estimation of runoff-rainfall ratio and land use change would not be able to use by substitution of other data. The equations were formulated based on only three factors of land use changes within 1989-1995, 1995-2000, and 2000-2004 period and runoff-rainfall ratio in study period of 1995, 2000, and 2004. To apply these equations from relationship between land use changes and runoff-rainfall ratio needs more time series periods for land use changes assessment.

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Table 4.11: R^2 values and equations of relationship between land use changes from paddy field to other land use types and runoff-rainfall ratio from using linear, power, and exponential models

Land use type	Standard error	Probability	r^2	Equation	Type of equation
A1-A2 (Paddy field to field crop)	0.831	0.034	0.069	$y= 0.198+0.082x$	Linear
	0.179	0.748	0.149	$y = 0.154x^{0.089}$	Power
	0.189	-	0.052	$y = 0.196e^{0.386x}$	Exponential
A1-A3 (Paddy field to perennial)	0.014	0.261	0.842	$y= -0.154x+0.202$	Linear
	0.071	0.237	0.868	$y = 0.147x^{-0.067}$	Power
	0.071	-	0.868	$y = 0.202e^{-0.853x}$	Exponential
A1-A4 (Paddy field to orchard)	0.021	0.066	0.644	$y= -0.084x+0.211$	Linear
	0.142	0.520	0.469	$y = 0.158x^{-0.109}$	Power
	0.110	-	0.678	$y = 0.213e^{-0.472x}$	Exponential
A1-A5 (Paddy field to horticultural land)	0.021	0.405	0.648	$y= -0.228x+0.203$	Linear
	-	-	-	-	Power
	0.110	0.382	0.682	$y = 0.203e^{-1.278x}$	Exponential
A1-A6 (Paddy field to shifting cultivated land)	0.017	0.313	0.777	$y= -0.053x+0.202$	Linear
	0.149	0.555	0.414	$y = 0.117x^{-0.041}$	Power
	0.086	-	0.806	$y = 0.202e^{-0.294x}$	Exponential
A1-F (Paddy field to forest)	0.029	0.619	0.318	$y= -0.929x+0.211$	Linear
	0.149	0.556	0.413	$y = 0.118x^{-0.121}$	Power
	0.165	-	0.284	$y = 0.202e^{-4.802x}$	Exponential
A1-M2 (Paddy field to wetland)	0.021	0.400	0.654	$y= -0.111x+0.203$	Linear
	-	-	-	-	Power
	0.109	0.055	0.688	$y = 0.203e^{-0.622x}$	Exponential
A1-U (Paddy field to community)	0.022	0.424	0.618	$y= -0.072x+0.205$	Linear
	0.164	0.638	0.290	$y = 0.168x^{-0.050}$	Power
	0.115	-	0.653	$y = 0.206e^{-0.405x}$	Exponential

Note: A1 = Paddy field A3 = Perennial crop A5 = Horticultural land
A2= Field crop A4 = Orchard A6 = Shifting cultivated land
F = Forest M2 = Wetland U = Community

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Table 4.11 showed that the land use type of paddy field to other land use type changes had not been related to runoff-rainfall ratio. In comparing the value of r^2 of paddy field to other land use types from using three models of linear, power, and exponential in order to prove the relation between those two variables, the results showed that all of r^2 values were very much less than 1. Therefore, the equations from land use changes from paddy field to other land use types do not have function to prove the relation.

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Table 4.12: R^2 values and equations of relationship between land use changes from field crop to other land use types and runoff-rainfall ratio from using linear, power, and exponential models

Land use type	Standard error	Probability	r^2	Equation	Type of equation
***A2-A1**	0.009	0.165	0.934	y= 0.053x+0.162	Linear
***(Field crop to**	***0.019***	***0.045***	***0.995***	***$y = 0.203x^{0.091}$***	***Power***
paddy field)	0.057	-	0.915	$y = 0.162e^{0.286x}$	Exponential
A2-A3	0.015	0.277	0.823	y= -0.060x+0.202	Linear
(Field crop to	0.103	0.072	0.720	$y = 0.159x^{-0.062}$	Power
perennial crop)	0.075	-	0.849	$y = 0.202e^{-0.333x}$	Exponential
A2-A4	0.031	0.685	0.226	y= -0.002x+0.200	Linear
(Field crop to	0.188	0.074	0.059	$y = 0.188x^{-0.013}$	Power
orchard)	0.168	-	0.257	$y = 0.200e^{-0.012x}$	Exponential
A2-A5	0.022	0.419	0.626	y= 0.076x+0.175	Linear
(Field crop to	-	-	-	-	Power
horticultural land)	0.124	0.057	0.591	$y = 0.174e^{0.402x}$	Exponential
A2-A6	0.026	0.512	0.481	y= -0.018x+0.203	Linear
(Field crop to	0.185	0.0797	0.099	$y = 0.182x^{-0.016}$	Power
shifting cultivated land)	0.135	-	0.518	$y = 0.203e^{-0.104x}$	Exponential
A2-F	0.026	0.530	0.453	y= -0.037x+0.204	Linear
(Field crop to	0.178	0.733	0.166	$y = 0.182x^{-0.037}$	Power
forest)	0.139	-	0.489	$y = 0.205e^{-0.208x}$	Exponential
A2-M2	0.027	0.548	0.425	y= -0.205x+0.207	Linear
(Field crop to	0.174	0.704	0.201	$y = 0.182x^{-0.055}$	Power
wetland)	0.143	-	0.461	$y = 0.205e^{-1.165x}$	Exponential
A2-U	0.021	0.407	0.645	y= 0.167x+0.106	Linear
(Field crop to	0.122	0.430	0.610	$y = 0.182x^{0.114}$	Power
community)	0.122	-	0.610	$y = 0.167e^{0.564x}$	Exponential

*the most r^2 value for each land use changes using three models

Note: A1 = Paddy field A3 = Perennial crop A5 = Horticultural land
A2 = Field crop A4= Orchard A6 = Shifting cultivated land
F = Forest M2 = Wetland U = Community

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The land use changes from field crop to other types of land use as independent variable and runoff-rainfall ration as dependent variable were used in order to conduct the relationship between those two variables. From viewing those changes from field crop to other land use types, the changes from field crop to paddy field had related to runoff-rainfall ratio (Table 4.12).

1) Relationship between changes from field crop to paddy field and runoff-rainfall ratio

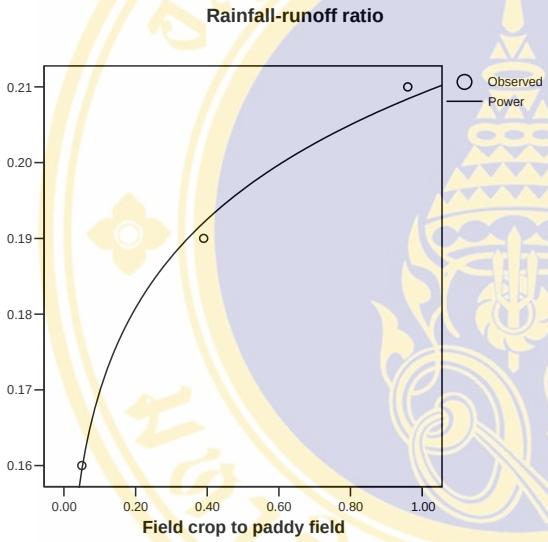

Figure 4.19: Relationship between changes from field crop to paddy field and runoff-rainfall ratio

In figure (4.19), probability 0.045 means 95.5% is possible so it is significant and the changes from field crop to paddy field affected on runoff-rainfall ratio.

Standard error of estimate 0.019 means that the figure can be believed as the figure is significant for more than 98%.

$r^2 = 0.995$

R^2 to measure overall variables (0.995) means that 99% of all explanatory variables land use changes from field crop to paddy field(x) can explain runoff-rainfall ratio (y), so there is strong relationship between x and y.

Coefficient (A2-A1) field crop to paddy field= 0.091

$y = 0.203x^{0.091}$

If 1% of field crop were converted to paddy field, runoff-rainfall ratio will increase 9.1%. Therefore, the equation had been proved that the change of field crop to paddy field related to the ratio of rainfall-runoff based on land use change and rainfall-runoff data from 1989 to 2004. In study area, some of paddy fields which do not need to water in growing season were grown in undulating terrain. Therefore, the area of field

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crop that consumed more water were changed to those kind of paddy field, the amount of water from rainfall can be captured by field crop.

Table 4.13: R^2 values and equations of relationship between land use changes from perennial crop to other land use types and runoff-rainfall ratio from using linear, power, and exponential models

Land use type	Standard error	Probability	r^2	Equation	Type of equation
A3-A1 (Perennial crop to paddy field)	0.008	0.139	0.953	$y= 0.116x+0.153$	Linear
	0.056	0.186	0.917	$y = 0.221x^{0.108}$	Power
	0.035	***0.116***	***0.967***	***$y = 0.154e^{0.639x}$***	***Exponential***
A3-A2 (Perennial to field crop)	0.008	0.150	0.945	$y= 0.020x+0.161$	Linear
	0.014	***0.046***	***0.995***	***$y = 0.190x^{0.097}$***	***Power***
	0.052	-	0.928	$y = 0.161e^{0.111x}$	Exponential
A3-A4 (Perennial to orchard)	0.030	0.650	0.273	$y= -0.006x+0.206$	Linear
	0.180	0.755	0.141	$y = 0.195x^{0.055}$	Power
	0.162	-	0.305	$y = 0.207e^{-0.034x}$	Exponential
A3-A5 (Perennial to horticultural land)	0.022	0.436	0.601	$y= -0.089x+0.175$	Linear
	-	-	-	-	Power
	0.128	0.459	0.565	$y = 0.174e^{0.471x}$	Exponential
A3-A6 (Perennial to shifting cultivated land)	***0.035***	***0.126***	***0.962***	***$y= -0.176x+0.244$***	***Linear***
	0.067	0.225	0.880	$y = 0.135x^{-0.269}$	Power
	0.045	-	0.946	$y = 0.253e^{-0.953x}$	Exponential
A3-F (Perennial to forest)	***0.012***	***0.073***	***0.987***	***$y= -0.100x+0.244$***	***Linear***
	0.054	0.180	0.923	$y = 0.156x^{-0.278}$	Power
	0.029	-	0.923	$y = 0.253e^{-0.544x}$	Exponential
A3-M2 (Perennial to wetland)	0.016	0.296	0.799	$y= -0.126x+0.202$	Linear
	0.123	0.436	0.600	$y = 0.155x^{-0.060}$	Power
	0.081	-	0.828	$y = 0.202e^{-0.698X}$	Exponential
A3-U (Perennial to community)	0.020	0.360	0.714	$y= -0.661x+0.229$	Linear
	0.111	0.387	0.674	$y = 0.095x^{-0.236}$	Power
	0.098	-	0.746	$y = 0.234e^{-3.695x}$	Exponential

*the most r^2 value for each land use changes using three models

Note: A1 = Paddy field A3 = Perennial crop A5 = Horticultural land
A2 = Field crop A4 = Orchard A6 = Shifting cultivated land
F= Forest M2= Wetland U = Community

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The land use changes from perennial crop to other types of land use as independent variable and runoff-rainfall ration as dependent variable were used in order to conduct the relationship between those two variables. From viewing those changes from field crop to other land use types, the changes from perennial crop to paddy field, field crop, and shifting cultivated land, and forest were described in detailed because they had the degree of believe r2 values explained the relationship near to 100% (Table 4.13).

1) Relationship between changes from perennial crop to paddy field and rainfall-runoff

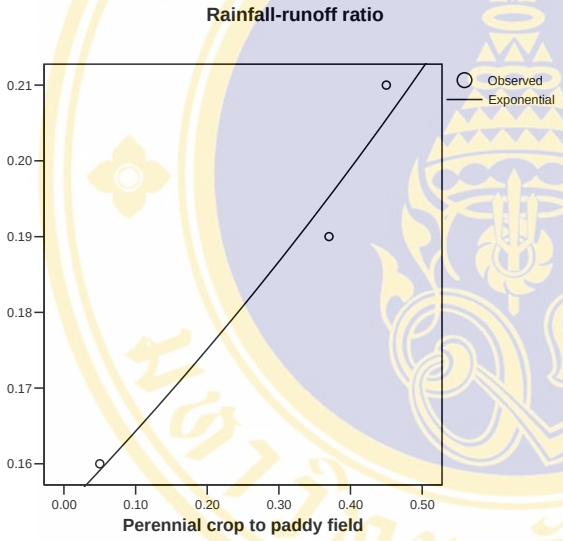

Figure 4.20: Relationship between changes from perennial crop to paddy field and runoff-rainfall ratio

Figure (4.20) showed that exponential regression model had applied with the inputs values of (0.45, 0.21), (0.05, 0.16) and (0.37, 0.19) from three periods during 1989 to 2004.

In figure (4.19), probability 0.116 means 88.4% is possible so it is insignificant and the changes from perennial crop to paddy field does not affect on runoff-rainfall ratio.

Standard error of estimate 0.035 means that the figure can be believed as the figure is significant for more than 96%.

$r^2 = 0.967$

Coefficient (A3-A1) perennial crop to paddy field= 0.639

$y = 0.154e^{0.639x}$

According to r^2 (0.967), it means nearly more than 96% of explanatory variable, changes from perennial crop to paddy field (x) can explain runoff-rainfall ratio (y). Although there is strong relationship between x and y, changes from perennial crop to paddy field does not affect on runoff-rainfall ratio as probability (0.116) means it was insignificant.

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2) Relationship between changes from perennial crop to field crop and rainfall-runoff

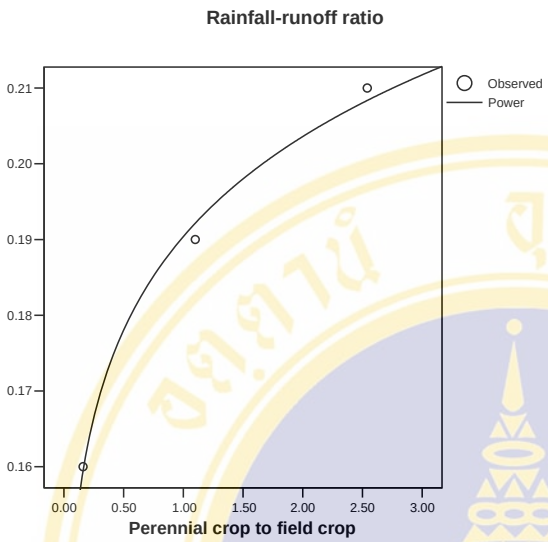

Figure 4.21: Relationship between changes from perennial crop to field crop and runoff-rainfall ratio

In figure (4.21), probability 0.046 means 95.4% is possible so it is significant and the changes from perennial crop to field crop affect on runoff-rainfall ratio.

Standard error of estimate 0.014 means that the figure can be believed as the figure is significant for more than 98%.

$r^2 = 0.995$

Coefficient (A3-A2) perennial crop to field crop= 0.097

$y = 0.190x^{0.097}$

If 1% of perennial crop were converted to field crop, runoff-rainfall ratio will increase 9.7%. The equation of perennial crop to field crop changes and runoff-rainfall ration was supposed to be used as their relationship was in goodness of fit and as well as probability (0.046) indicated 95.4% is possible so the changes from perennial crop to field crop affected on runoff-rainfall ratio.

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3) Relationship between changes from perennial crop to shifting cultivated land and rainfall-runoff

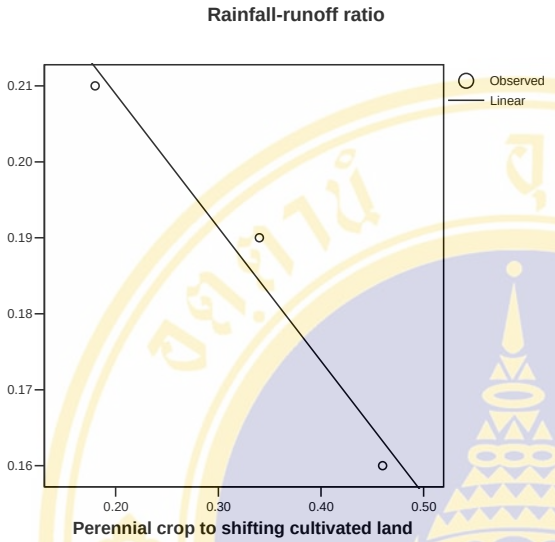

Figure 4.22: Relationship between changes from perennial crop to shifting cultivated land and runoff-rainfall ratio

In figure (4.22), x and y value of three points (0.18,0.21), (0.46,0.16), and (0.34, 0.19) were used as inputs from three periods 1989-1995, 1995-2000, and 2000-2004 to find out the relationship between the changes from perennial crop to shifting cultivated land (A3-A6) and runoff-rainfall ratio using linear regression methods.

From this analysis, probability 0.126 means 87.4% is possible so it is insignificant and the changes from perennial crop to shifting cultivated land does not affect on runoff-rainfall ratio.

Standard error of estimate 0.035 means that the figure can be believed as the figure is significant for more than 98%.

$r^2 = 0.962$

Coefficient (A3-A6) perennial crop to shifting cultivated land = -0.176

y= -0.176x+0.244

If 1% of perennial were converted to shifting cultivated land, runoff-rainfall ratio will decrease 17.6%. It was observed that although r^2 (0.962) indicated strong relationship; probability (0.126) showed that it was insignificant between changes from perennial crop to shifting cultivated land and runoff-rainfall ratio.

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4) Relationship between changes from perennial crop to forest and runoff-rainfall ratio

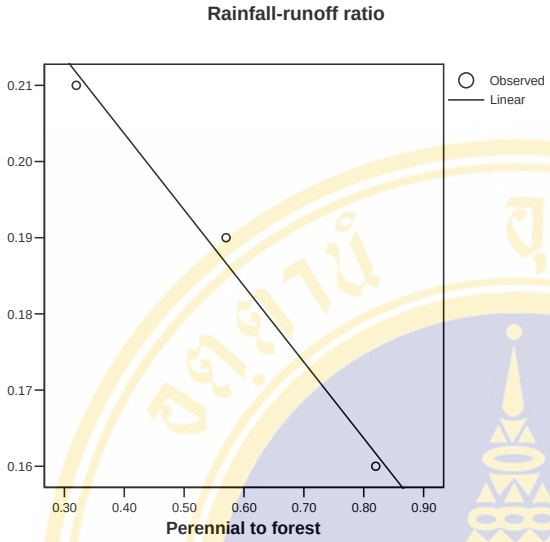

Figure 4.23: Relationship between changes from perennial crop to forest

In figure (4.23), probability 0.73 means 27% is only possible so it is insignificant and the changes from perennial crop to forest does not affect on runoff-rainfall ratio.

Standard error of estimate 0.012 means that the figure can be believed as the figure is significant for more than 98%.

$r^2 = 0.987$

Coefficient (A3-F) perennial crop to forest = 0.1

$y = -0.100x+0.244$

If 1% of perennial crop were converted to forest, runoff-rainfall ratio will decreases 10%. However, it was insignificant to explain the perennial crop to forest changes that did not effect on runoff-rainfall ratio as probability was (0.73).

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Table 4.14: R^2 values and equations of relationship between land use changes from orchard to other land use types and runoff-rainfall ratio from using linear, power, and exponential models

Land use type	Standard error	Probability	r^2	Equation	Type of equation
A4-A1 (Orchard to paddy field)	0.035	0.950	0.006	y= -0.003x+0.185	Linear
	-	-	-	-	Power
	0.193	0.926	0.013	$y = 0.184e^{0.023x}$	Exponential
A4-A2 (Orchard to field crop)	0.035	0.910	0.020	y= -0.0004x+0.185	Linear
	0.147	0.547	0.426	$y = 0.198x^{0.024}$	Power
	0.191	-	0.031	$y = 0.183e^{0.003x}$	Exponential
A4-A3 (Orchard to perennial crop)	***0.016***	***0.118***	***0.966***	***y= -0.087x+0.212***	***Linear***
	-	-	-	-	Power
	0.043	0.141	0.952	$y = 0.212e^{-0.470x}$	Exponential
A4-A5 (Orchard to Horticultural land)	0.022	0.415	0.633	y= 0.025x+0.175	Linear
	0.151	0.565	0.398	$y = 0.202x^{0.033}$	Power
	0.123	-	0.598	$y = 0.174e^{0.133x}$	Exponential
A4-A6 (Orchard to shifting cultivated land)	0.027	0.537	0.442	y= 0.012x+0.155	Linear
	0.119	0.420	0.624	$y = 0.159x^{0.176}$	Power
	0.141	-	0.478	$y = 0.155e^{0.066x}$	Exponential
A4-F (Orchard to forest)	0.035	0.945	0.008	y= 0.001x+0.185	Linear
	0.194	0.965	0.003	$y = 0.185x^{0.006}$	Power
	0.193	-	0.015	$y = 0.183e^{0.004x}$	Exponential
A4-M2 (Orchard to wetland)	0.026	0.528	0.457	y= -0.643x+0.206	Linear
	-	-	-	-	Power
	0.148	0.551	0.421	$y = 0.205e^{-3.372x}$	Exponential
A4-U (Orchard to community)	0.036	0.990	0.000	y= -0.012x+0.187	Linear
	-	-	-	-	Power
	0.194	0.990	0.000	$y = 0.185e^{0.068x}$	Exponential

*the most r^2 value for each land use changes using three models

Note: A1 = Paddy field A3= Perennial crop A5 = Horticultural land
A2= Field crop A4 = Orchard A6 = Shifting cultivated land
F= Forest M2 = Wetland U = Community

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The land use changes from orchard to other types of land use as independent variable and runoff-rainfall ration as dependent variable were used in order to conduct the relationship between those two variables. From viewing those changes from orchard to other land use types, the changes from orchard to perennial crop was described in detailed because it had almost the degree of believe r^2 values explained the relationship near to 100% (Table 4.14).

1) Relationship between changes from orchard to perennial and rainfall-runoff

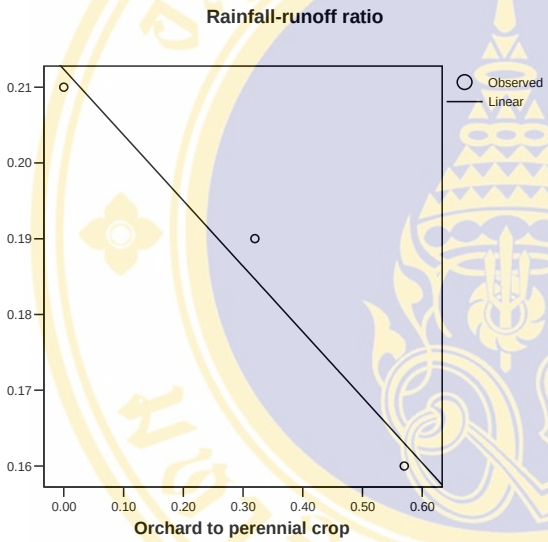

Figure 4.24: Relationship between changes from orchard to perennial crop and runoff-rainfall ratio

In order to know the relationship between changes from orchard to perennial crop, linear model was applied with the inputs value (0, 0.21), (0.57, 0.16), and (0.31, 0.19) from three period from 1989 to 2004. In figure (4.24), probability 0.118 means 88.2% is possible so it is insignificant and the changes from orchard to perennial crop does not affect on runoff-rainfall ratio. Standard error of estimate 0.016 means that the figure can be believed as the figure is insignificant for more than 98%.

$r^2 = 0.966$

Coefficient (A4-A3) forest to perennial = -0.087

$y = -0.087x+0.212$

Although r^2 that indicated that there was strong relationship between changes from orchard to perennial crop and runoff-rainfall ratio, according to probability (0.118) that mean it was insignificant to explain the changes from orchard to perennial crop that affect on runoff-rainfall ratio.

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Table 4.15: R^2 values and equations of relationship between land use changes from horticultural land to other land use types and runoff-rainfall ratio from using linear, power, and exponential models

Land use type	Standard error	Probability	r^2	Equation	Type of equation
A5-A1 (Horticultural land to paddy)	0.004	0.066	0.989	y= 0.188x+0.157	Linear
	0.175	0.175	0.926	$y = 0.223x^{0.073}$	Power
	0.013	***0.043***	***0.996***	***$y = 0.158e^{1.031x}$***	***Exponential***
A5-A2 (Horti- field crop)	0.023	0.456	0.568	y= 0.023x+0.173	Linear
	0.169	0.670	0.245	$y = 0.196x^{0.039}$	Power
	0.133	-	0.532	$y = 0.173e^{0.121x}$	Exponential
A5-A3 (Horti-perennial)	0.011	0.202	0.902	y= -0.434x+0.203	Linear
	-	-	-	-	Power
	0.054	*0.179*	*0.923*	*$y = 0.203e^{-2.399x}$*	*Exponential*
A5-A4 (Horti-orchard)	0.035	0.882	0.034	y= -0.001x+0.192	Linear
	0.192	0.895	0.027	$y = 0.186x^{-0.008}$	Power
	0.190	-	0.048	$y = 0.192e^{-0.007x}$	Exponential
A5-A6 (Horti-shifting cultivated land)	0.016	0.303	0.790	y= -0.100x+0.203	Linear
	0.121	0.427	0.614	$y = 0.155x^{-0.069}$	Power
	0.083	-	0.819	$y = 0.202e^{-0.559x}$	Exponential
A5-F (Horti-forest)	0.017	0.308	0.784	y= -0.335x+0.221	Linear
	0.094	0.320	0.768	$y = 0.114x^{-0.203}$	Power
	0.084	-	0.813	$y = 0.225e^{-1.862x}$	Exponential
A5-M2 (Horti-wetland)	0.017	0.313	0.694	y= -0.046x+0.202	Linear
	0.151	0.0564	0.816	$y = 0.169x^{-0.039}$	Power
	0.056	-	0.660	$y = 0.202e^{0.257x}$	Exponential
A5-U (Horti-community)	0.019	0.373	0.017	y= 0.110x+0.171	Linear
	0.083	0.282	0.045	$y = 0.232x^{0.082}$	Power
	0.113	-	0.027	$y = 0.171e^{0.586x}$	Exponential

*the most r^2 value for each land use changes using three models

Note: A1 = Paddy field A3 = Perennial crop A5 = Horticultural land
A2= Field crop A4 = Orchard A6 = Shifting cultivated land
F Forest M2 = Wetland U = Community

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The land use changes from horticultural land to other types of land use as independent variable and runoff-rainfall ration as dependent variable were used in order to conduct the relationship between those two variables. From viewing those changes from horticultural land to other land use types, the changes from horticultural land to paddy field, and perennial crop were described in detailed because they had the degree of believe r2 values explained the relationship near to 100% (Table 4.15).

1) Relationship between changes between horticultural land to paddy field and rainfall-runoff

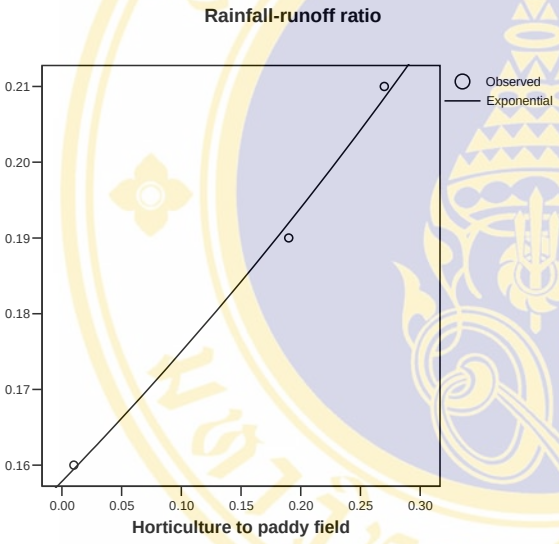

Figure 4.25: Relationship between changes from horticultural land to paddy field and runoff-rainfall ratio

Figure (4.25) showed that exponential model was applied to consider relationship between changes from horticultural land to paddy field (A5-A4) and runoff-rainfall ratio based on the input of those data in the three periods within 1989-2004. In the figure, the first, x and y value (0.27, 0.21), second (0.01, 0.16), and third point (0.19, 0.19) were inputs for different periods of 1989-1995, 1995-2000, and 2000-2004. The value of x represented as percentage of land use change from horticultural land to forest and y represented as runoff-rainfall ratio for each period.

In figure 4.24, probability 0.043 means 95.7 is possible so it is significant and the changes from horticultural land to paddy field affected on runoff-rainfall ratio.

Standard error of estimate 0.013 means that the figure can be believed as the figure is significant for more than 98%.

$r^2 = 0.995$

Coefficient (A5-A1) horticultural land to paddy field = 1.030

$y = 0.1579e^{1.030x}$

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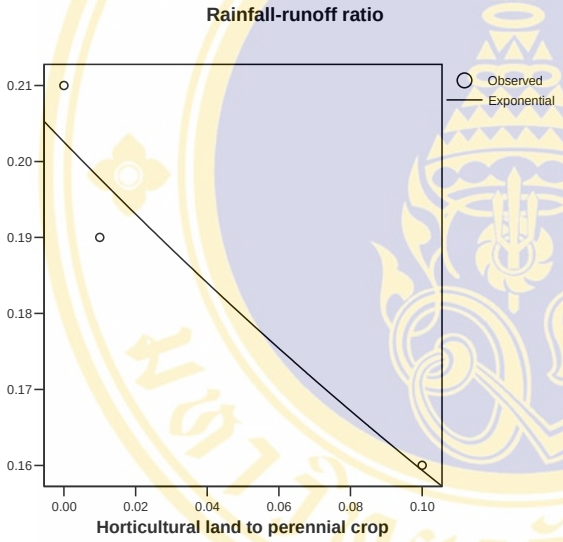
If 1% of horticultural land were converted to paddy field, runoff-rainfall ratio will increase 103%. According to r^2 (0.995), it means nearly more than 99% of explanatory variable, changes from horticultural land to paddy field (x) can explain runoff-rainfall ratio (y). Therefore, there is strong relationship between x and y, those changes had affect on runoff-rainfall ratio as probability (0.043) means it was significant and the changes can explain runoff-rainfall ratio 95.7%.

2) Relationship between changes from horticultural land to perennial and runoff-rainfall ratio



In figure (4.26), probability 0.179 means 82.1% is possible so it is insignificant and the changes from horticultural land to perennial crop does not affect on runoff-rainfall ratio.

Standard error of estimate 0.054 means that the figure can be believed as the figure is insignificant for less than 95%.

$r^2 = 0.922$

Figure 4.26: Relationship between horticultural land to perennial crop and runoff-rainfall ratio

Coefficient (A5-A3) horticultural land to perennial crop= -2.399

$y = 0.203e^{-2.399x}$

According to r^2 (0.992) that indicated there was strong relationship between changes from horticultural land to perennial crop, but probability (82.1) that mean it was insignificant and horticultural land to perennial crop changes did not have affect on runoff-rainfall ratio.

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Table 4.16: R^2 values and equations of relationship between land use changes from shifting cultivated land to other land use types and runoff-rainfall ratio from using linear, power, and exponential models

Land use type	Standard error	Probability	r^2	Equation	Type of equation
A6-A1 (Shifting-paddy)	0.035	0.918	0.017	$y= 0.009x+0.184$	Linear
	0.190	0.864	0.045	$y = 0.193x^{0.020}$	Power
	0.192	-	0.027	$y = 0.183e^{0.064x}$	Exponential
A6-A2 (Shifting-field crop)	0.035	0.872	0.040	$y= 0.004x+0.183$	Linear
	0.160	0.614	0.325	$y = 0.194x^{0.040}$	Power
	0.189	-	0.055	$y = 0.181e^{0.024x}$	Exponential
A6-A3 (Shifting-perennial)	0.012	0.225	0.880	$y= -0.032x+0.202$	Linear
	-	-	-	-	Power
	0.059	***0.202***	***0.903***	$\boldsymbol{y = 0.202e^{-0.179x}}$	***Exponential***
A6-A4 (Shifting-orchard)	***0.002***	***0.029***	***0.998***	$\boldsymbol{y= -0.016x+0.224}$	***Linear***
	0.056	0.187	0.916	$y = 0.207x^{-0.168}$	Power
	0.016	-	0.993	$y = 0.228e^{-0.090x}$	Exponential
A6-A5 (Shifting-horticultural land)	0.025	0.488	0.518	$y= 0.047x+0.174$	Linear
	0.186	0.806	0.300	$y = 0.194x^{0.019}$	Power
	0.140	-	0.482	$y = 0.173e^{0.245x}$	Exponential
A6-F (Shifting-forest)	0.016	0.293	0.803	$y= -0.020x+0.215$	Linear
	0.112	0.390	0.670	$y = 0.183x^{-0.072}$	Power
	0.093	-	0.773	$y = 0.216e^{-0.105x}$	Exponential
A6-M2 (Shifting-wetland)	0.011	0.202	0.902	$y= -0.434x+0.207$	Linear
	0.010	***0.056***	***0.992***	$\boldsymbol{y = 0.125x^{-0.111}}$	***Power***
	0.054	-	0.923	$y = 0.208e^{-2.400x}$	Exponential
A6-U (Shifting-community)	0.11	0.204	0.901	$y= -0.140x+0.205$	Linear
	0.004	***0.029***	***0.998***	$\boldsymbol{y = 0.144x^{-0.096}}$	***Power***
	0.055	-	0.921	$y = 0.206e^{-0.772x}$	Exponential

*the most r^2 value for each land use changes using three models

Note: A1 = Paddy field A3 = Perennial crop A5 = Horticultural land
A2 = Field crop A4 = Orchard A6 = Shifting cultivated land
F= Forest M2 = Wetland U = Community

The land use changes from shifting cultivated land to other types of land use as independent variable and runoff-rainfall ration as dependent variable were used in

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order to conduct the relationship between those two variables. From viewing those changes from shifting cultivated land to other land use types, the changes from shifting cultivated land to perennial crop, orchard, wetland, and community were described in detailed because they had the degree of believe r2 values explained the relationship near to 100% (Table 4.16).

1) Relationship between changes from shifting cultivated land to perennial crop and runoff-rainfall ratio

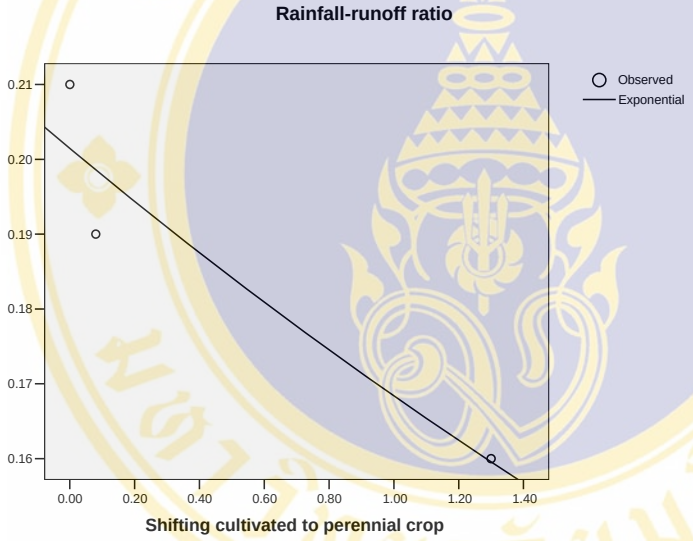

Figure 4.27: Relationship between shifting cultivated land to perennial crop and runoff-rainfall ratio

In figure (4.27), probability 0.202 means 79.8% is possible so it is insignificant and the changes from shifting cultivated land to perennial crop does not affect on runoff-rainfall ratio.

Standard error of estimate 0.059 means that the figure cannot be believed as the figure is insignificant for less than 95%.

$r^2 = 0.922$

Coefficient (A6-A3) shifting cultivated land to perennial crop= -0.179

$y = 0.201e^{-0.179x}$

Although r^2 that indicated that there was strong relationship between changes from shifting cultivated land to perennial crop and runoff-rainfall ratio, according to probability (0.202) that mean it was insignificant to explain the changes from shifting cultivated land to perennial crop that affect on runoff-rainfall ratio.

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2) Relationship between changes between shifting cultivated land to orchard and rainfall-runoff

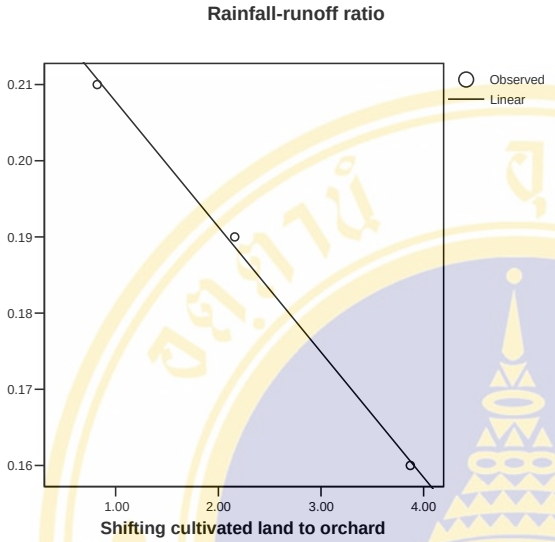

Figure 4.28: Relationship between changes from shifting cultivated land to orchard and runoff-rainfall ratio

- Significant can be determined if the probability ≤ 0.05
- Standard error ≤ 0.05 means we believe that the figure is significant more than 95%
- r^2 tells that the degree of believe and it can be used them for residuals

In figure (4.28), probability 0.029 means 97.1 is possible so it is significant and the changes from shifting cultivated land to orchard have affect on runoff-rainfall ratio. Standard error of estimate 0.001 means that the figure can be believed as the figure is significant for more than 99%.

$r^2 = 0.998$

Coefficient (A6-A4) shifting cultivated land to orchard = -0.016

y= -0.016x+0.224

If 1% of shifting cultivated land were converted to orchard, runoff-rainfall ratio will decrease to 1.64%. Moreover, the changes from shifting cultivated land to orchard had affect on runoff-rainfall ratio according to probability (0.029) as well as degree of believe ($r^2 = 0.998$) showed strong relationship in order to prove changes from shifting cultivated land to orchard (x) can explain the rainfall-runoff (y) 99%.

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3) Relationship between changes from shifting cultivated land to wetland and rainfall-runoff

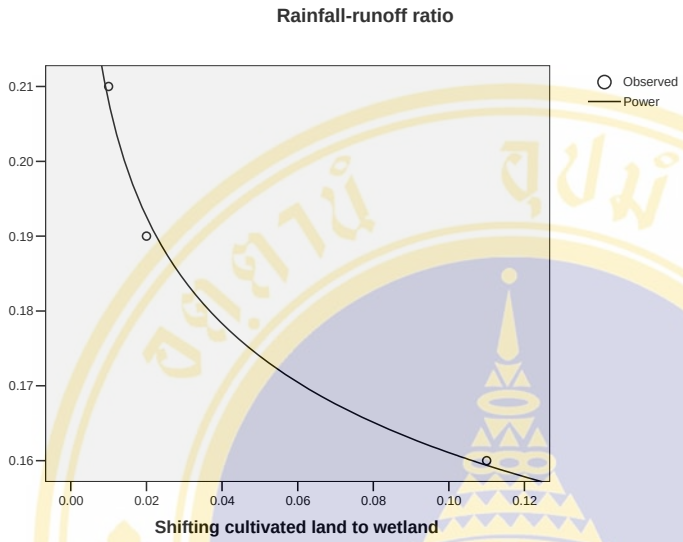

Figure 4.29: Relationship between shifting cultivated land to wetland and runoff-rainfall ratio

In figure (4.29), power method was used to consider the relationship between shifting cultivated land to wetland. In this analysis the value of changes from shifting cultivated land to wetland (0.01), (0.11), and (0.02) and the magnitude of runoff-rainfall ratio (0.21), (0.16), and (0.19) were considered.

In figure (4.28), probability 0.056 means 94.4% is possible so it is insignificant and the changes from shifting cultivated land to wetland does not affect on runoff-rainfall ratio.

Standard error of estimate 0.010 means that the figure can be believed as the figure is significant for equal to 99%.

$r^2 = 0.992$

Coefficient (A6-M2) shifting cultivated land to wetland= -0.111

$y = 0.125x^{-0.111}$

Regarding to r^2 (0.992), the changes from shifting cultivated land to wetland can prove to explain the runoff-rainfall ratio 99%. However, the probability (94.4%) that means insignificant to explain shifting cultivated land to wetland changes did not have affect on rainfall-runoff.

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4) Relationship between changes from shifting cultivated land to community and rainfall-runoff

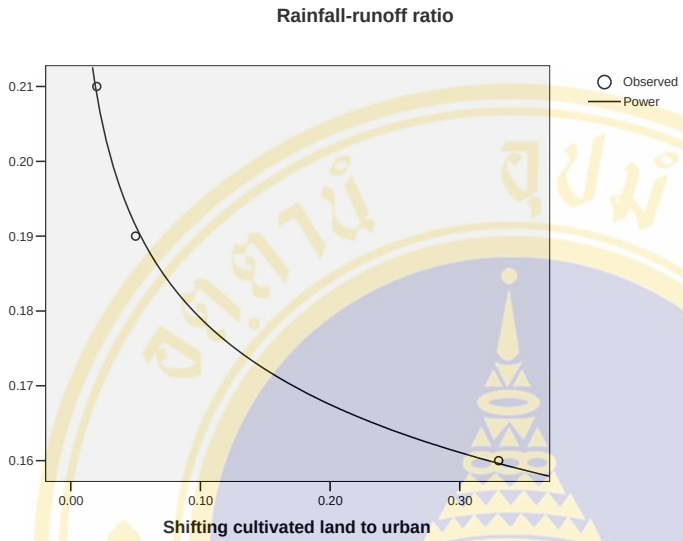

Figure 4.30: Relationship between changes from shifting cultivated land to community and runoff-rainfall ratio

In considering the relation, the percentages of changes were (0.02), (0.33), and (0.02) respectively. Similarly, the percentage of runoff-rainfall ratio were (0.21), (0.16), and (0.19).

In figure (4.30), probability 0.029 means 97.1% is possible so it is significant and the changes from shifting cultivated land to community had affect on runoff-rainfall ratio.

Standard error of estimate 0.004 means that the figure can be believed as the figure is significant for more than 99%.

r^2 = 0. 0.998

Coefficient (A6-U) shifting cultivated land to community= -0.096

$y = 0.143x^{-0.096}$

If 1% of shifting cultivated lands were converted to community, runoff-rainfall ratio will decrease 9.6%. In the case, there was strong relationship between changes from shifting cultivated land to community and runoff-rainfall ratio by r^2 = 0. 0.998. It means land use changes can explain the runoff-rainfall ratio 99% as well as the probability (0.029) means that 97.1% is possible the changes had affect on runoff-rainfall ratio.

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Table 4.17: R^2 values and equations of relationship between land use changes from forest to other land use types and runoff-rainfall ratio from using linear, power, and exponential models

Land use type	Standard error	Probability	r^2	Equation	Type of equation
F-A1 (Forest-paddy field)	0.035	0.843	0.060	y= 0.163x+0.182	Linear
	-	-	-	-	Power
	0.187	0.819	0.078	$y = 0.181e^{1.017x}$	Exponential
F-A2 (Forest-field crop)	0.033	0.736	0.162	y= 0.006x+0.178	Linear
	0.104	0.360	0.713	$y = 0.193x^{0.038}$	Power
	0.175	-	0.190	$y = 0.176e^{0.033x}$	Exponential
F-A3 (Forest-perennial)	***0.061***	***0.101***	***0.975***	***y= -0.382x+0.212***	***Linear***
	-	-	-	-	Power
	0.441	0.125	0.962	$y = 0.213e^{-2.074x}$	Exponential
F-A4 (Forest-orchard)	0.002	0.039	0.996	y= -0.005x+0.227	Linear
	0.030	0.986	0.976	$y = 0.282x^{-0.208}$	Power
	0.004	***0.016***	***0.999***	$y = 0.232e^{-0.026x}$	***Exponential***
F-A5 (Forest-horticultural land)	0.026	0.528	0.457	y= 0.643x+0.174	Linear
	-	-	-	-	Power
	0.148	0.074	0.421	$y = 0.173e^{3.372x}$	Exponential
F-A6 (Forest-shifting)	0.035	0.854	0.052	y= 0.004x+0.180	Linear
	0.179	0.742	0.155	$y = 0.185x^{0.061}$	Power
	0.188	-	0.069	$y = 0.178e^{0.273x}$	Exponential
F-M2 (Forest-wetland)	0.018	0.340	0.740	y= -0.182x+0.202	Linear
	-	-	-	-	Power
	0.093	0.317	0.771	$y = 0.202e^{-1.013x}$	Exponential
F-U (Forest-community)	0.019	0.369	0.701	y= 0.251x+0.173	Linear
	-	-	-	-	Power
	0.112	0.391	0.667	$y = 0.173e^{1.339x}$	Exponential

*the most r^2 value for each land use changes using three models

Note: A1 = Paddy field A3 = Perennial crop A5 =Horticultural land
A2 = Field crop A4 = Orchard A6 = Shifting cultivated land
F = Forest M2 = Wetland U = Community

The land use changes from forest to other types of land use as independent variable and runoff-rainfall ration as dependent variable were used in order to conduct the relationship between those two variables. From viewing those changes from forest to

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other land use types, the changes from forest to perennial crop, and orchard were described in detailed because they had the degree of believe r^2 values explained the relationship near to 100% (Table 4.17).

1) Relationship between changes from forest to perennial crop and rainfall-runoff

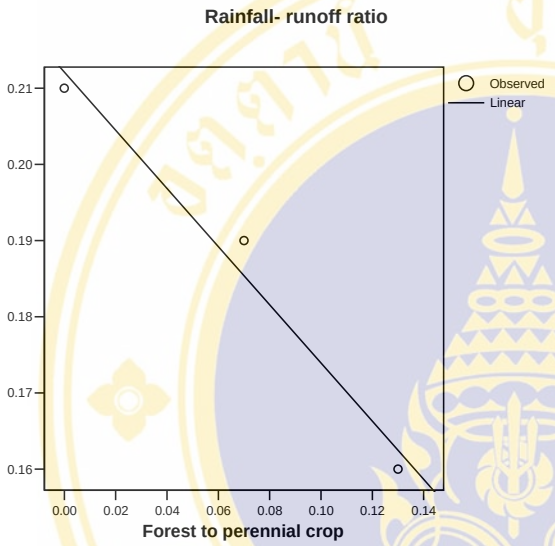

Figure 4.31: Relationship between changes from forest to perennial crop and runoff-rainfall ratio

In consideration of relationship between changes from forest to perennial crop and runoff-rainfall ratio, x and y value (0.00, 0.21), (0.13, 0.16), and (0.07, 0.19) were used as input from the period of 1989-1995, 1995-2000, and 2000-2004.

In figure (4.31), probability 0.101 means 89.9% is possible so it is insignificant and the changes from forest to perennial crop does not affect on runoff-rainfall ratio.

Standard error of estimate 0.061 means that the figure can be believed as the figure is significant for more than 99%.

$r^2 = 0.975$

Coefficient (F-A3) forest to perennial = -0.382

y= -0.382x+0.212

It can be noticed that changes from forest to perennial crop did not have affect on runoff-rainfall ratio as the probability (0.1010 that means it is insignificant. Therefore, the changes can not explain the runoff-rainfall ratio although the degree of believe was 97%.

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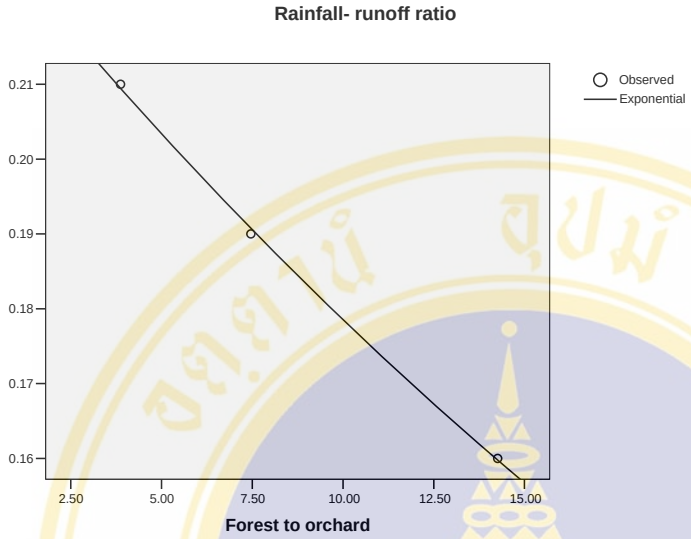
2) Relationship between changes between forest to orchard and rainfall-runoff



In figure (4.32), probability 0.016 means 98.4 is possible so it is significant and the changes from forest to orchard had affect on runoff-rainfall ratio.

Standard error of estimate 0.001 means that the figure can be believed as the figure is significant for more than 99%.

$r^2 = 0.999$

Figure 4.32: Relationship between changes from forest to orchard and runoff-rainfall ratio

Coefficient (F-A4) forest to orchard = -0.026

$y = 0.232e^{-0.026x}$

If 1% of forest land is converted to orchard, runoff-rainfall ratio will decrease 2.6. According to r^2 (0.999), it means nearly more than 99% of explanatory variable, changes from forest to orchard (x) can explain runoff-rainfall ratio (y). Therefore, there is strong relationship between x and y, changes from forest to orchard had affect on runoff-rainfall ratio as probability (0.016) means it was significant and the changes can explain runoff-rainfall ratio 98.4%.

4.6.1 Most relationship between land use change and runoff-rainfall

According to degree of believe (r^2) $\geq$ 0.9, there were (14) types of land use changes that can explain the runoff-rainfall ratio. However, only (6) types of land use changes can explain their changes were related to runoff-rainfall ratio among all of changes within each other by comparing of linear, power, and exponential models. It was noticed that the changes from field crop to paddy field, perennial crop to field crop, and shifting cultivated land to community were indicated the relationship using power

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model. Similarly, the changes from horticultural land to paddy field, and forest to orchard were enable to explain the relationship using exponential model while shifting cultivated land to orchard was related to runoff-rainfall ratio using linear. Therefore, it was observed that power and exponential model were more applicable to explain the relationship between land use changes and runoff-rainfall ratio in Mae Taeng watershed during the study period 1989-2004.

Table 4.18: Relationship between land use changes and runoff-rainfall ratio

No	Land use type	Type of equation	Probability	Effect
1	Field crop-Paddy(A2-A1)	Power	Significant	Increase
2	Perennial-Paddy (A3-A1)	Exponential	Insignificant	-
3	Perennial-Field crop (A3-A2)	Power	Significant	Increase
4	Perennial- Shifting (A3-A6)	Linear	Insignificant	-
5	Perennial-Forest (A3-F)	Linear	Insignificant	-
6	Orchard-Perennial (A4-A3)	Linear	Insignificant	-
7	Horticultural-Paddy (A5-A1)	Exponential	Significant	Increase
8	Horticultural-Perennial (A5-A3)	Exponential	Insignificant	-
9	Shifting-Perennial (A6-A3)	Exponential	Insignificant	-
10	Shifting-Orchard (A6-A4)	Linear	Significant	Decrease
11	Shifting-Wetland (A6-M2)	Power	Insignificant	-
12	Shifting-Community (A6-U)	Power	Significant	Decrease
13	Forest-Perennial (F-A3)	Linear	Insignificant	-
14	***Forest-Orchard (F-A4)**	**Exponential**	**Significant**	**Decrease**

* **Strong relationship among relationship between land use changes and runoff rainfall ratio**

____ Significant

Table (4.18) showed that fourteen land use changes were selected based on r^2 value. However, among land use changes, only six types of land use changes (underline) are

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significant. Of them the changes from forest to orchard was one of the most relationships between land use changes and runoff-ratio.

4.8 Impact of Land use change on runoff

Based on the analysis of relationship between land use change and runoff, it was observed that the conversion of forest to orchard could be concerned the practice of land preparation in the site proposed for orchard. Orchard is the intentional planting of trees or shrub maintained for fruit production. Most orchards comprised either fruit or nut-producing trees for commercial production. Particularly, most orchards grown tropical fruit like banana, mango and papaya often concentrated near bodies of water to fulfill the requirement of water for those fruit trees. As it was also one of the factors like the selection of species for orchard, perennial and horticultural crop, the magnitude of runoff varies from juvenile to mature stage. During those periods, cultivation technique of certain species is also one of the major concerns in assessment of runoff from the aspect of land use practice in Mae Taeng watershed.

The causes of changes from forest to other land use class were complex. It was recognized that increasing demand for paddy field, orchard and other field crop created community to get more income opportunities for improvement of living people in that area. With the development of their job opportunities, there has been growing population growth among the traditional settler. Notwithstanding there were large changes from other to paddy fields that directly proportional to the high rainfall-runoff, the changes from other land use to paddy field were declined throughout the study period. It was observed that intensive agricultural practices which is an agricultural production system characterized by the significant use of inputs, and seeking to maximize the production. It relies on the use of chemical fertilizers, herbicides, fungicides, insecticides, plant growth regulators, pesticides as well as in creasing use of modern practices and agricultural mechanization. Consequently, the impact of mechanization often enhanced the cultivated land to compact by the intensive use of mechanical power. Moreover, cultivated soil subjected to repeated use throughout the year. That impact caused rapidly topsoil lost and became impoverish

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soil, due to soil erosion and poor conservation practices. Thus more overland flow is generated and less rain percolates to deeper layers.

After reviewing impact of land use changes on runoff, how land use practice is suitable for such kind of land use is major issues to consider in mitigating on water resource. As soil erosion resulting from traditional methods of cultivation on slopes steeper than 35 percent is much greater than the tolerance limit, selection of site for cultivation should be considered as a major role of conservation. Especially, permanent plantations like mango grown on slope area, cause severe in the first year but this decline in subsequent years if there were effective erosion control measures, such as grass-strips, intercropping and landslide ditches which can effectively reduce soil erosion.

Land use change in watershed area that is difficult to reintroduce permanent trees as cleared and cultivated areas cannot be changed back to forest as well as the land has been used by local residents for agriculture. Owing to mountainous region, it was essential to conserve the existing forests to be avoiding the reducing forest cover. However, that current rate of forest land use change to other creates reducing the quality of forest in the study area. Moreover, conversion of forest to other land use was also one issue caused by shifting cultivation which a patch of land is cultivated for a short period, then left to fallow for several years while the shifting cultivators move on to work on another piece of land. Shifting cultivation is a form of substance farming; it needed enough fallow periods to allow soil properties to recover under conditions of natural successional stages of re-growth.

4.9 Conclusion

This chapter summarized the results of the study. The rainfall was estimated within the range of 1000-1600 mm. The correlation of runoff and rainfall showed that there was strong relation between those variables as the result revealed it was significant. Land use results revealed that majority of area were covered by forest in Mae Taeng watershed in the study period 1989, 1995, and 2004 except in 2000. The trend of land

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use change from each land use to other was observed that the changes form orchard to other land use were the most among changes from each land use type to other. Moreover, results revealed that reducing area of forest related to runoff-rainfall ratio as 99% of total variation in runoff-rainfall ratio can be explained by the relationship between changes from forest to orchard and runoff-rainfall ratio.

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CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

The purpose of this chapter is to describe the findings from the analysis of rainfall and runoff as well as assessment of land use change during the study period from 1989 to 2004. Similarly, this chapter will summarize relationship between land use changes and runoff-rainfall ratio as a result of finding for the study.

5.1 Summary of Major Findings

As a conclusion of this study, the finding was concluded based on the main objectives of this study i) rainfall and runoff in the Mae Taeng watershed, ii) land use and land cover situation in the Mae Taeng watershed, and iii) relationship between land use changing and runoff-rainfall ratio.

5.1.1 Rainfall and runoff in Mae Taeng watershed

Estimation of areal rainfall for Mae Taeng watershed had been carried out based on point rainfall from four rain gage stations. It was concluded that

- Annual rainfall was within a range 1000-1600 mm based on four study periods
- Magnitude of runoff was correlated with rainfall based on four study period

5.1.2 Land use and land cover change situation in the Mae Taeng watershed

The findings from land use and land cover in study area indicated that the proportion of land use and land cover differed in each study period. There were three period of land use change form 1989 to 2004. From knowing how much land use type have in each period, land use trend throughout the study periods revealed that each land use class varied in the form of fluctuation throughout the year. Especially, forest converted to other land use rapidly while shifting cultivation decrease in changes because

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orchard and horticulture were occupied in shifting cultivated land. Therefore, the shifting cultivated lands were gradually reduced throughout the study period even through percentage of area was still in high proportion. The trend of forest area was declined from 1989 to 2004 during the prominent increase of orchard followed by field crop changes. As area of paddy field was located near the area where the Mae Taeng flow through from North to South, the change of paddy field within the study period was slightly altered compared to other land use class. It was concluded that:

- From 1989 to 1995, area of forest occupied in Mae Taeng was in high proportion of land coverage followed by the coverage of orchard
- From 1995 to 2000, forest increased than last period and still in high land coverage. However, forest land cover declined during the period of 1995 to 2000, as orchard was increased to high percentage
- From 2000 to 2004, even though forest cover still declined than last period, there was high proportion of forest cover followed by orchard and field crop area

5.1.3 Relationship between land use changing and runoff-rainfall ratio

By overlaying two periods of land use class gave the changes from one to other land use type. As nine land-use classes were taken into account in classification of land use for the study area, there were 81 land use changes for analysis of relationship between those changes and runoff-rainfall ratio. In order to analyze the relationship linear, power and exponential model were applied. The results from relationships showed different coefficients of regression from each model. Among them, forest to orchard changes revealed that there was strong relation between the changes from forest to orchard and runoff-rainfall ratio.

In Mae Taeng watershed, most of the area was occupied by a large amount of forests composed of hill evergreen, mixed deciduous forest, and pine forest since a couple of decades. Although most of the land was demarcated as protected area system classified into national part and wildlife sanctuary, some parts of forest area were changing in almost every year. From assessing the changes of land in Mae Taeng watershed, forest area were converted to different use of land from 1989 to 2004 study period. It was concluded that:

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- If the area of forest to orchard change were small in initial period, rainfall-runoff was also in high magnitude
- Similarly, if the changes were in large amount of area, runoff-rainfall ratio in those periods was in low magnitude

5.1.4 Hypotheses

Two hypotheses of the study stated in chapter 1 were such i) land use changes were mostly occurred in forest land to other ii) Reducing the area of forest related to runoff-rainfall ratio. From the results of discussion of section 4.4 explained in chapter 4 revealed that changes from orchard to other land use more than changes from forest to other, therefore it was concluded that: hypothesis 1 was rejected. However, being the result and discussion of section 4.6.1 explained the variation in runoff-rainfall ratio can be explained by the relationship between changes from forest to orchard and runoff-rainfall ratio, hypothesis 2 was accepted.

5.2 Limitation of study

The study of this research was limited to analysis in different components of data including acquisition of satellite image that are required for land use change assessment and runoff and requirement of more ground check points.

5.2.1 Detailed data requirement for runoff

Especially, more detailed description on the runoff would be provided whether the magnitude of runoff depend on precipitation or other impact including changes in land use, if satellite image could be available for each period of land use change. Similarly, runoff analysis was limited as the way to analyze runoff from the aspect of peak flow, base flow, ground flow and overland flow although the magnitude of runoff was available for throughout the study period.

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5.2.2 Limited number of ground check points for training area

The study to validate accuracy assessment for land use classification had performed using in a few number of ground check point for each land use class. It would better to get more accuracy if possible to do a sufficient number of points to cover the whole study area.

5.2.3 Different time period in acquisition of satellite images

The time acquired each satellite image was not the same period so that it was difficult to classify land use classes. Since the study focused on land use change from 1989 to 2004, in identification of land use type for previous it was difficult to support actual land use type at that time. However, this study used the method of previous supervised classification to classify for previous times.

5.2.4 Limited number of data to analyze relationship

As this study based on time period 1989-1995, 1995-2000, and 2000-2004, there were limited number of data to analyze the relationship. However, the numbers of data depend on satellite image that was acquired to interpret land use/cover situation in that period. If it is possible to get time series data of land use/cover, it would contribute more accurate result of relationship between land use changes and runoff-rainfall ratio.

5.3 Recommendation

As has been discussed in this chapter the impacts of land use change on runoff can be mitigated during the process of land preparation for one to other land use type in a way of using sound land use practices. Therefore, an efficient land use practice towards conservation of land and water resources is recommended, in order to entirely distribute water throughout the year. It is recommended to improve soil conservation measures aiming at to maximize the impacts of land use on water resources. Land use practice aimed at sustainable resource use to be implemented is concerned in initial

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stage of their process in different land use type. Therefore, it is recommended that the implementation of such activities agriculture development, road building result in the removal of vegetation, which can result in increased run-off should toward with the objectives of sustainable resource and environmental management.

5.3.1 Suitable Land use practice

In fact watershed management cannot be achieved if the land resources of soil, water and vegetation in isolation from each other. They formed a dynamic and integrated bio-physical, economic, social, environmental and political system containing population, agriculture, industry, communications and recreational facilities. As has already been explained in above mention about relationship between land use change and runoff-rainfall ratio, land use changes can causes of significant changes on water resources in term of runoff. These changes produce more or less effects upon the runoff of the Mae Taeng watershed, which can lead to degradation of natural resources of watershed and an increase in the intensity of natural disaster like flood in downstream. However, the vulnerability of watersheds to land degradation and water-related natural disaster can be minimized by land treatment measures and land use practices. Land use practices comprised a variety of farming, cropping and cultivation techniques whose purposes are to maintain a protective vegetative cover, to increase infiltration and to impede overland flow.

In initial stage of land preparation to start to grow orchard trees, it is necessary to conserve soil erosion. Moreover, more effective erosion control can be achieved through supplementary cultivation in the form of listing or ridging, which involves the formation of alternating furrows and ridges on the cultivated land. This is most effective when the formation is undertaken strictly on the contour, where it serves not only to reduce soil erosion but also to reduce run-off and improve soil moisture conservation. In study area although there were terracing structure in slightly undulating area where intensive paddy field were occupied, most of orchard without terrace structure in slightly hillside area had been observed in ground checking assessment. Of a wide variety of terrace-like structures for erosion control under a

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range of topographic and farming conditions suitable structure should be employed. If terrace, artificial embankments, or combined embankments and channels were constructed across slopping land, which can perform runoff diversion, runoff detention, the slow-down of overland flow velocity, the reduction of erosive slope length, improved infiltration and soil moisture retention and slope stabilization.

From identifying the impact of land use change on runoff, the relationship can provide effective results in taking into account in watershed management from the aspect of land use change. Land use changes in Mae Taeng watershed where vegetation cover was converted by clearing land in the forest leaded to land degradation which caused alternation in ecosystem as well as contribute to the reduction of the value of the land for human and ecological purposes. Therefore, the natural balance of resources in watershed can be easily disrupted by changes in land use.

5.3.2 Appropriate conservation practices

It was recommended that land use practice is important as the use of appropriate practices, and land treatment measures can provide effective in reducing amount of runoff in intense storm events. The practice apply to slope area, including orchard, horticulture and shifting cultivation, appropriate temporary measures, such as erosion control blankets, silt barriers or mulches, could be used as appropriate during the establish period. Moreover, vegetative barriers can be used to stabilize steep slopes.

5.3.3 Land treatment measures

By using appropriate land use practice, it can retard runoff, increase the infiltration rate, improve production and enhance the productivity of the land. Similarly, land treatment measures like large-scale structural measures such as flood mitigation such as flood mitigation reservoirs, channel modification can be effective in mitigating the impact of water-related natural disaster. The most requirements for land treatment measures are to provide and maintain a dense, protective vegetative cover for as much of the time as possible. Moreover, special cropping methods and tillage practices can

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be employed to minimize the time periods during which the ground must be unprotected during land preparation and seed planting or after harvesting, or to reduce the total area of ground exposed to erosive rainfall at any time. In addition, retard runoff and reduce the erosive energy of overland flow.

5.3.4 Further research

Further research required for collection of components of watershed and as well as detailed information of crop calendar for the study area. The whole components of watershed such as rainfall, overland flow, base flow, ground water discharge, temperature, evapotranspiration, humidity are major parts in watershed management. This study aimed the impact of land use change on runoff from quantity of water resources. However, the climatological factors were limited to analysis into detailed explanation between the relationship such as temperature and humidity for estimation of evapotranspiration. For next research should be focused on relationship between land use change and their consequences on runoff from the aspect of soil, vegetation cover type changes. Moreover, the impact of land use changes on water quality due to which individual land use class has different effects of their managing systems.

From knowing the result of this study, the reducing the area of forest was directly effected on reducing amount of runoff-rainfall ratio. Hence, it is need to apply suitable land use practice emphasize on less pressure on reducing area of forest along with efficient water usage. Considering the implementation of suitable land use practice, it is need to be considered on possible land use of the study area and introduced to local community such as agroforestry. Some important aims of agroforestry are; increased productivity/income, improved equity in benefit-sharing, and sustainable upland management. To work effective with local people, researches and development workers must be able to approach agroforestry from a farming system perspective. Therefore, both local people and research should test and validate the aims, potential and positive interaction among both socioeconomic and ecological component.

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5.4 Final comments

This study attempted to estimate runoff and annual rainfall, and land use changes from 1989-2004 in Mae Taeng watershed. The results revealed that the reducing area of forests had effect of decreasing magnitude of runoff-rainfall ration based on three time periods data of land use change assessment. In order to maintain efficient water usage, it was recommended that suitable land use practices such as agroforestry, land treatment measures, special cropping methods which could help achieving of conservation of water resources, but also promote maintenance of ecological system.

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APPENDIX

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APPENDIX 1a: RAIN GAGE STATIONS DISTRIBUTION IN MAE TAENG WATERSHED

Name of station	Location	Average annual rainfall	Recorded period (Years)	Type of data
Mae Ho Phra Forest Plantation	19˚04′ 99˚13′	1128.39	1980-2000	Daily, monthly
Wiang Haeng		1126.50	1989-2004	Daily, monthly
Mae Taeng	19˚12′ 98˚95′	1129.98	1952-2003	Daily, monthly
Fang	19˚55′2″ 99˚13′	1228.53	1980-2000	Daily, monthly
Doi Chiang Dao Watershed Research	19˚16′7″ 98˚58′32″	1029.47	1980-2000	Daily, monthly
Mae Ho Phra Forest Plantation	19˚04′ 99˚13′	1063.54	1980-2000	Daily, monthly
Mae Hong Son	19˚18′ 97˚50′	1312.42	1997-2002	Daily, monthly
Chiang Rai	18˚47′ 98˚59′	1732.23	1997-2002	Daily, monthly
Chiang Mai	19˚55′ 99˚50′	1128.63	1997-2002	Daily, monthly

APPENDIX 1b: RAIN GAGE STATION - 07112 MAE TAENG, CHIANG MAI

	1989	1995	2000	2004
Jan	0	0	0	2
Feb	0	20.3	0	15.76
March	0	26	0	14.88
April	24.3	105.2	57.7	24.78
May	107.2	206.4	143.2	204.5
June	174.7	140.4	164.7	111.03
July	195.3	311.9	152.4	194.5
August	143.7	341.8	89.7	175.76
Sep	198.4	226.4	109.2	132.81
Oct	103	64.4	144.4	114.21
Nov	38.2	119	2.3	73.11
Dec	0	0	0	15.44
Annual Rainfall	984.8	1561.8	863.6	1078.78

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APPENDIX 1c: RAIN GAGE STATION – 07702 WIANG HAENG, CHIANG MAI

	1989	1995	2000	2004
Jan	0	0	10.6	0
Feb	30.3	41	0	0
March	13.5	5.7	71.4	4
April	0	72.1	122.3	0
May	127	206.3	308.7	228
June	120.8	107.7	103.64	116.5
July	163.1	335.2	264.3	275
August	242.4	310.6	134.2	216.1
Sep	194.32	180.3	131	272.9
Oct	13.1	72	58.2	0
Nov	2.3	67.9	0	10.1
Dec	0	0	0	0
Annual Rainfall	906.82	1398.8	1204.34	1122.6

APPENDIX 1d: RAIN GAGE STATION – 07252 DOI CHIANG DAO WATERSHED RESEARCH

	1989	1995	2000	2004
Jan	0.7	0	12.9	0
Feb	11.5	0	0	0
March	1.5	0	104.9	23.2
April	6.0	52.5	69.2	57.4
May	149.6	189.4	230.7	254.5
June	174.0	195.7	270.1	224.1
July	299.8	347.3	176.4	373.3
August	178.6	415.3	217.4	290.9
Sep	279.0	330.4	174.0	448.9
Oct	173.3	110.7	173.0	39.4
Nov	57.5	36.7	2	29.7
Dec	0	0	2	0
Annual Rainfall	1331.5	1678	1432.6	1741.4

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APPENDIX 1e: RAIN GAGE STATION - 07102 FANG

	1989	1995	2000	2004
Jan	0	0	11.4	0
Feb	30.2	76.6	0	0
March	16.6	4	80.6	79.9
April	9.7	40.5	130.2	131.7
May	149.5	124.0	172.8	309.9
June	157.9	93.3	208.9	177.5
July	243.3	273.8	258.3	222.4
August	221.0	525.2	148.9	214.2
Sep	151.4	312.4	125.3	448.7
Oct	106.7	15.9	124.2	108.7
Nov	20.6	62.0	0	14.4
Dec	0	0	0	0
Annual Rainfall	1106.9	1527.7	1260.6	1707.4

APPENDIX 1f: MAGNITUDE OF RAINFALL FROM FOUR RAIN GAGE STATIONS

Year	Wiang Haeng (502.26 km^2)	Mae Taeng (318.94 km^2)	Doi Chiang Dao Watershed Research (432.93 km^2)	Fang (700.08 km^2)	Annual Rainfall (mm)
1989	906.82	980.8	1331.5	1106.9	1084.7
1995	1398.8	1561.8	1678	1527.7	1533.4
2000	1204.34	863.6	1432.6	1260.6	1302
2004	1122.6	1078.78	1741.4	1707.4	1462

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APPENDIX 2: LAND USE/ COVER CRITERIA OF LAND CLASSIFICATION

Class id/ name	Description
1 Paddy Field	A field planted with rice growing in water
2 Field crop	a crop (other than fruits or vegetables) that is grown for agricultural purposes; "cotton, hay, and grain are field crops"
3 Perennial crop	Plant that lives for more than 2 growing seasons
4 Orchard	An orchard is an intentional planting of trees or shrubs maintained for food production, fruit or nut-producing trees, for commercial production
5 Horticulture	The cultivation of fruit, flowers, vegetables and shrubs
6 Shifting Cultivated land	Shifting cultivated land where a forested area is cleared, burnt, and cultivated, then left abandoned to allow natural regrowth before beginning again
7 Forest	A forest is an area with a high density of trees
8 Wetland	Land that is seasonally or permanently covered by shallow water, or land where the water table is close to or at the surface
9 Community	man-made structures

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