SPATIAL MODELING FOR SOIL EROSION ASSESSMENT IN UPPER LAM PHRA PHLOENG WATERSHED, NAKHON RATCHASIMA, THAILAND

Ugyen Thinley

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แบบจำลองเชิงพื้นที่สำหรับการประเมินการพังทลายของดิน ในลุ่มน้ำลำพระเพลิงตอนบน นครราชสีมา ประเทศไทย

นายอูเก็น ทินเลย์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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อูเก็น ทินเลย์ : แบบจำลองเชิงพื้นที่สำหรับการประเมินการพังทลายของดิน ในลุ่มน้ำลำพระเพลิงตอนบน นครราชสีมา ประเทศไทย (SPATIAL MODELING FOR SOIL EROSION ASSESSMENT IN UPPER LAM PHRA PHLOENG WATERSHED, NAKHON RATCHASIMA, THAILAND) อาจารย์ที่ปรึกษา : อาจารย์ ดร.สุวิทย์ อ๋องสมหวัง, 125 หน้า

การประมาณการกระจายตัวเชิงพื้นที่ของการพังทลายของดินในภูมิทัศน์เป็นเรื่องสำคัญยิ่งในปัจจุบันด้วยเหตุผลหลายประการ วัตถุประสงค์ของการศึกษาคือ การประเมินการสูญเสียดินเชิงพื้นที่และการให้คำแนะนำแก่นักพัฒนาที่ดินเพื่อลดปัญหาการการเสื่อมโทรมของดินในพื้นที่ศึกษา การบูรณาการการรับรู้จากระยะไกลและระบบสารสนเทศภูมิศาสตร์เข้ากับสมการการสูญเสียดินสากล (USLE) สำหรับประเมินการพังทลายของดินถูกดำเนินการในพื้นที่ลุ่มน้ำลำพระเพลิงตอนบน นครราชสีมา โดยนำข้อมูลภาพดาวเทียม Landsat-TM ที่บันทึกในปี พ.ศ. 2543 และ พ.ศ. 2551 มาจำแนกโดยเทคนิคผสม เพื่อจำแนกประเภทการใช้ประโยชน์ที่ดินและสิ่งปกคลุมดิน เพื่อนำไปใช้สร้างแผนที่ปัจจัยการจัดการพืช และปัจจัยการปฏิบัติการป้องกันการชะล้างพังทลายในสมการ USLE รวมทั้ง การจัดสร้างแผนปัจจัยที่ควบคุมการพังทลายของดินอื่น ที่ประกอบด้วย ปัจจัยของน้ำฝนและการไหลบ่า ความยาวและความชันของความลาดเท และความคงทนต่อการถูกชะล้างพังทลายของดิน จากข้อมูลปริมาณน้ำฝนเฉลี่ยรายปี ข้อมูลแบบจำลองความสูงเชิงเลข ข้อมูลชุดดินและธรณีวิทยา ตามลำดับ

ผลที่ได้รับจากการศึกษาหลักได้แก่ แผนที่การใช้ที่ดินและสิ่งปกคลุมดิน ปี พ.ศ. 2543 และ พ.ศ. 2551 แผนที่การเปลี่ยนแปลงการใช้ประโยชน์ที่ดินและสิ่งปกคลุมดินที่ระบุถึงการเปลี่ยนแปลงที่เกิดขึ้นระหว่าง ปีพ.ศ. 2543 และ พ.ศ. 2551 รวมทั้ง ผลิตแผนที่การพังทลายของดิน ปี พ.ศ. 2543 และ พ.ศ. 2551 ที่อาศัยแบบจำลองการสูญเสียดินสากล จากผลที่ได้รับพบว่า ปริมาณการพังทลายของดินที่เกิดขึ้นในปี พ.ศ. 2543 มีมากกว่า ปี พ.ศ. 2551 โดยมีสาเหตุหลักมาจากปริมาณน้ำฝนเฉลี่ยรายปีสูงกว่า นอกจากนี้ ระดับความรุนแรงของการพังทลายของดินถูกจำแนกออกเป็น 5 ระดับ ประกอบด้วย ต่ำมาก ต่ำ ปานกลาง รุนแรง และรุนแรงมาก โดยพบว่า ในปี พ.ศ. 2543 พื้นที่การพังทลายของดินระดับปานกลาง รุนแรง และรุนแรงมาก คิดเป็นเนื้อที่ 150.59 ตร. กม. (19.25%) 44.43 ตร. กม. (5.68%) และ 0.15 ตร. กม. (0.02%) ตามลำดับ ในขณะที่ ในปี พ.ศ. 2551 พื้นที่การพังทลายของดินระดับปานกลาง รุนแรง และรุนแรงมาก คิดเป็นเนื้อที่ 139.54 ตร. กม. (17.84%) 41.84 ตร. กม. (5.35%) และ 0.12 ตร. กม. (0.02%) ตามลำดับ ในบริเวณที่มีการพังทลายของดินในระดับปานกลาง รุนแรงและรุนแรงมาก ต้องมีมาตรการอนุรักษ์ดินและน้ำเป็นพิเศษ รวมทั้ง การจัดทำแผนที่การเปลี่ยนแปลงระดับความรุนแรงของการพังทลายของดินระหว่างปี พ.ศ. 2543 และ

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SOIL EROSION/ GIS/ REMOTE SENSING/ USLE/ LAND DEGRADATION

Estimating spatial distribution of soil erosion in the landscape has become very critical in the present day world for various reasons. The study basically aimed to spatially model soil loss and to provide guidance to land developers for reducing land degradation problem in the study area. The integration of RS/GIS with Universal Soil Loss Equation (USLE) for soil erosion assessment has been carried out in Upper Lam Phra Phloeng watershed in Nakhon Ratchasima. Herewith, two Landsat-5 TM imageries in 2000 and 2008 were classified by using hybrid techniques for land use and land cover classes for vegetation cover and field support practice factors of USLE. Also, other USLE factors included rainfall-runoff erosivity, slope length and steepness, erodibility factors were extracted based on mean annual rainfall, DEM, soil and geological data under GIS, respectively.

Two land use and land cover maps in 2000 and 2008 were prepared. The land use and land cover change map was generated indicated change of amount from 2000 to 2008. Also, soil loss maps in 2000 and 2008 were produced based on USLE model

พ.ศ. 2551 เพื่อแสดงอัตราการเพิ่มขึ้นและลดลงของการพังทลายของดินที่เกิดขึ้น นอกจากนี้ พบว่า ผลผลิตตะกอนเฉลี่ยที่ประเมินได้จากสัดส่วนของตะกอนที่ถูกพัดพาสู่ลำน้ำ (SDR) ในปี พ.ศ. 2543 และ พ.ศ. 2551 คิดเป็นปริมาณ 12.84 ตัน/เฮกตาร์/ปี และ 12.03 ตัน/เฮกตาร์/ปีตัน ตามลำดับ

สาขาวิชาการรับรู้จากระยะไกล ลายมือชื่อนักศึกษา_______________________

ปีการศึกษา 2551 ลายมือชื่ออาจารย์ที่ปรึกษา_________________

and the result indicated that the amount of soil loss in 2000 is more than 2008 as rainfall intensity was high. Furthermore, severity of soil loss was classified into 5 classes include very low, low, moderate, severe and very severe. The result obtained 150.59 sq. km (19.25%) *moderate*, 44.43 sq. km (5.68%) *severe* and 0.15 sq. km (0.02%) *very severe* in year 2000. While the result obtained 139.54 sq. km (17.84%) *moderate*, 41.84 sq. km (5.35%) *severe* and 0.12 sq. km (0.02%) *very severe* in year 2008. *Moderate, severe* and *very severe* locations were here emphasized for the soil and water conservation practices. The change of soil loss severity between 2000 and 2008 map was also generated for indicating both increase and decrease in soil loss rate. In addition, an average sediment yield in 2000 and 2008 based on site specific Sediment Delivery Ratio (SDR) were 12.84 ton/ha/year and 12.03 ton/ha/year respectively.

School of Remote Sensing Student's Signature____________________

Academic Year 2008 Advisor's Signature____________________

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ACCRONYMS AND ABBREVIATIONS

AGNPS	Agricultural Non-Point Source
ANSWERS	Areal Nonpoint Source Watershed Environment Response Simulation
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Management Systems
DEM	Digital Elevation Model
DMR	Department of Mineral Resources
EUROSEM	The European Soil Erosion Model
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GISTDA	Geo-Informatics and Space Technology Development Agency
GPS	Global Positioning System
GUESS	Griffith University Erosion Sedimentation System
Ha	Hectare
Km	Kilometer
LDD	Land Development Department
LULC	Land Use and Land Cover
mm	Millimeter
MSL	Mean Sea Level
MUSLE	Modified Universal Soil Loss Equation
RMMF	Revised Morgan Morgan and Finney
RS	Remote Sensing

ACCRONYMS AND ABBREVIATIONS (Continued)

RTSD	Royal Thai Survey Department
RUSLE	Revised Universal Soil Loss Equation
SLEMSA	Soil Loss Estimation Model for Southern Africa
TM	Thematic Mapper
TMD	Thai Meteorological Department
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
WEPP	Water Erosion Prediction Project
μm	Micrometer

CHAPTER I

INTRODUCTION

1.1 General background of soil erosion

Soil is the basis of production and world's economic still relies on agricultural sector. Despite numerous efforts, the agricultural soil loss is a grave concern and it is a world-wide problem. Soil erosion is widely considered to be a serious threat to the long-term viability of agriculture in many parts of the world (El-Swaify *et al*., 1985**).** Soil erosion, the most serious type of land degradation, occurs in all climatic regions. Soil degradation is a broader term for a decline in soil quality encompassing the deterioration in physical, chemical and biological attributes of the soil, which may be enhanced by, among other things, accelerated soil erosion (Eaton, 1996).

Erosion by water is a primary agent of soil degradation at the global scale, affecting 1,094 m hectares, or roughly 56% of the land experiencing human induced degradation (Oldeman *et al.*, 1991). It is estimated that crop productions become uneconomical on 20 m hectares of land worldwide annually (Elirehema, 2001). For example, there are approximately 107 m rai or 33% of the whole country accounted to erosional loss of nutrients, minerals and organic matters in Thailand (http://www.ldd.go.th).

Therefore, the study of soil erosion patterns in the landscape and interactions among the major factors that affect this process is essential, particularly in humid mountainous areas (Hoyos, 2005). This is due to their steep topography and frequent high rainfall amounts and intensities, it is wise to design sound conservation measures.

Many high priorities natural resource conservation projects throughout the world depends upon accurate erosion assessments and predictions (Onstand and young, 1988). For erosion study, various data on long-term rainfall, soil and geological formation, terrain (topography), land use and land cover mapping are the basic essentials for the assessment. Such information will enable to prevent soil loss before it is severely damaged from various sources of degradation. Unfortunately, these types of information are not much readily available in many developing countries.

Erosion prediction models can help address long-term land management planning under natural and agricultural conditions. Even though it is hard to find a model that considers all forms of erosion, many models were developed specifically to aid conservation planners in identifying areas where introducing soil conservation measures will have the most impact on reducing soil loss. There are several methods of quantitative assessment of soil erosion. The models differ greatly in structure and data requirements. For practical application, models of low complexity are most desirable.

Spatial assessment of soil erosion can basically be done in three different ways (Vrieling, 2007). The first is to measure soil erosion rates at different locations using some measuring device or erosion plots. This might be very expensive task. The second approach is the execution of erosion field surveys with identifiable features that were formed due to erosion processes using soil loss indicators. The measurement result from these results will vary due to their time scale change involved in its formation. The third and most common method for spatial erosion assessment is through integrating spatial data on erosion factors. Widely-used is the Universal Soil

Loss Equation (Wischmeier and Smith, 1978). This is the cost effective method in understanding the distribution of erosion problem. The study carried here is the best example.

Since the development of the Universal Soil Loss Equation (USLE) by Wischmeier and Smith (1978), the soil loss modeling has been extensively used in many parts of the world. It became popular because of its simplicity and low data requirements. It has become most particularly useful in evaluating the impacts of intensified land use on soil loss. USLE is factor-based (Laflen *et al*., 1991), which means that a series of factors, each quantifying one or more processes and their interactions, are combined to yield an overall estimate of soil loss. It is designed to predict long-term average annual soil loss from field slopes under a specific land use and management system, based on the product of rainfall erosivity (R), soil erodibility (K), slope length (L), steepness (S), surface cover and management (C) and support conservation practices (P).

Traditionally, the USLE model has been initially designed for use for local conservation planning at an individual farm scale in gently sloping cropland applications. But nowadays, it is applied in many parts of the world with some modifications in the local factors. Therefore, it can alert the soil managers to potential erosion hazards and identify the factors responsible for excessive soil loss and aid in selecting an appropriate conservation practices.

Coupling GIS and USLE has been widely used and is very effective approach for estimating the magnitude of soil loss and identifying the spatial locations vulnerable to soil erosion (Fu *et al*., 2006; Lim *et al*., 2005). Remote Sensing complimented with field ground truthing and GIS provide the best methodological toolset to investigate soil erosion (Wolfgang, 2002).

1.1.1 Statement of soil degradation problem

The soil loss situation in the Northeastern part of Thailand has become very crucial due to increased intensity of mechanized cultivation and clearing of forests, which has led to soil erosion problems. Similarly, soil erosion in Lam Phra Phloeng watershed is identified as a major problem by LDD (LDD, 2000).

Due to the influx of more and more people, the agricultural land since then has expanded rapidly. This type of land conversion from natural vegetation to agricultural land uses is often perceived as environmentally degrading, in terms of declining the soil quality. With the passage of time, the decline in natural soil fertility is found in the area, where more and more fertilizers were applied to maintain the crop yield level. The application of inorganic fertilizers, herbicides and pesticides became standard practice as it greatly increased agricultural production. However, the inorganic fertilizers have provided negative impact of risking and polluting the surface water leading to other environmental hazards.

Literature provides information on non-utilization of inorganic fertilizers in early 1960s and 1970s. The practice of applying this type of fertilizers came from 1980s. It is all because of soil degradation due to erosion, which is accredited to clearing and cultivation of forestland, and due to improper use of agricultural land that has lead to deterioration of the physical, chemical and biological properties of soils.

Farmers in the area are not aware of the soil erosion process and its effects in the long-term quality of the soils. So, no major erosion prevention and soil protection measures have been practiced. If the current trend is allowed or being continued, there will be reduced family income and agricultural outputs in the study area. Regarding on agricultural land use practices, the farmers have changed from animal powered tillage to tractor drawn land-preparation. This has lead to more intensive soil mixing and deeper tillage with its direction often across the contour, thus encouraging soil erosion (Cho and Zoebisch, 2003). Another problem is after the crop has been harvested; the land is tilled and left fallow for quite some time and becomes sensitive to sheet erosion. Farmers especially in the upper part of the watershed grow corn as the main crop from May to December (Chandraprabha, 2002) and land is completely left fallow and abandoned after harvest from January to April making susceptible to erosion. These types of problems are of grave concern for the long term sustainability of the finite land natural resources.

The truth of soil degradation and severe soil loss in the study area can be better understood with many indicators found in the area. Indicators are variables which may show that land degradation has taken place – they are not necessarily the actual degradation itself. The piling up and contributing sediments against a down-slope water body like Lam Phra Phloeng dam can be an 'indicator' that land degradation is occurring upslope. Similarly, decline in yields of a crop may be an indicator that soil quality has changed, which in turn may indicate that soil and land degradation are also occurring. Another thing is the need of more fertilizers. The condition (change of texture and colour) of the soil is one of the best indicators of land degradation. Similarly there are sets of indicators that can be found in the area like: rills, gullies, pedestals, armour layer, plant/tree root exposure, exposure of below ground portions of fences and other structures (for sheet erosion), rock exposure, tree mounds, built-up against barriers etc..

It should be clearly noted that none of these measures are directly comparable with each other. However, after careful scrutiny, they can be used to ascertain general trends in land degradation (Stocking and Murnaghan, 2000). For example, tree mounds formed under trees of different ages can tell us whether degradation is getting worse, staying more or less the same, or even starting to reverse. Rocks can also yield information useful over longer timescales. In contrast, the buildup of soil against field barriers such as boundary walls tells us what has happened in that field since the walls were constructed.

Single indicator gives singular item of evidence for land degradation or its impact. They are susceptible to error, misinterpretation and chance. Therefore, by combining indicators, more robust conclusions can be entertained, even to the extent that quite different types of measure may be placed alongside each other to obtain a fuller understanding as to whether land degradation is happening. Similarly, the indicators were clearly visible indicating and confirming the degradation, even though the field measurements could not be done due to time and financial constraints. However, it should be noted that calculations of the absolute levels of soil erosion from all indicators are simple but require ample time.

Farmers were also not aware of the effect of change of land use and management practices in erosion prevention but they kept on changing the land use ever since from 1960s. This was due to change in marketing opportunities and decline in soil productivity. Earlier, people cultivated rice and vegetables after clear-cutting the forests. However, later when rice came cheaply in the market from other areas due to more viability of transport services, people began to cultivate maize as labour requirement was not expensive as that of rice and they could earn enough cash with maize plantation twice a year. Then in early 1970s, when there was good market for mangoes, people started to plant mango trees. By the time, when the trees started giving fruits after several years, its market has really gone down. This was because; farmers did not have idea, equipments and resources. Later the quality of mango declined and again after several years, most people started uprooting and converting it again for maize plantation in late 1980s and early 1990s.

As of year 2000, the main field crop was mainly corn; however with increase in market opportunities, cassava and sugarcane with other cash crop are grown. If we closely analyze into the land use change, there would be greater impacts on variations in the soil loss requiring conservations and support practices.

1.1.2 Significance of soil erosion on agricultural productivity

The relationship between soil erosion and agricultural productivity is complex and involves many different factors. By altering soil properties, erosion has direct effects on crop production. Erosion can decrease soil fertility, organic matter in the soil and plant-available water reserves (Lal, 1987). Thus, the exposed soil remaining will be less productive in a physical sense. These effects may be cumulative and not observed for a long period of time will cause more depletion. Quantifying the effects of erosion on crop production faces many difficulties.

First of all, the extent to which erosion affects crop production will vary depending on the type of crop, the type of soil, the micro-climate, local topography and the management system (Lal, 1987). Secondly, it is extremely difficult to determine the influence of any single factor on crop yields. Any attempt to measure the effect of erosion on yields will be almost impossible to control for other effects, such as variations in precipitation. Therefore, long-term data is essential however, since the effects of erosion on productivity will change throughout the soil profile (Stocking, 1984).

However, an estimate or approximate crop yield from a specific spot can be better understood, when the quantity of erosion level in different locations of the study area is obtained from the USLE result from integrations of all factors. Therefore, the agricultural production will be low in places where the erosion level is high and better yield in the areas where the erosion is less.

1.1.3 Significance of soil erosion and sediment yield on environment

Soil erosion is the first step in the sedimentation processes, which consist of erosion, transportation and deposition of sediment. It can carry sediments, nutrients, and pesticides to surface water bodies, degrading water quality. Sediments may make water cloudy destroying breeding areas for aquatic life and decreasing their ability to find their food. Soilborne pesticides may kill, deform, or harm aquatic life. Soilborne nutrients may also stimulate the growth and decomposition of algae, resulting in a lack of oxygen for fish. Sediments from erosion may clog drainage ditches, road ditches, and culverts and contribute to silt loading of streams and areas behind dams. Sediment yields are also associated with waterway damages. Sediment deposition in streams reduces channel capacity and result in flooding damages. The water storage capacity of reservoirs can be depleted by accumulated sediment deposition. Effective erosion control and sediment containment begin with the project planning process (Toy *et al*., 1998). Controlling sediment loading requires the knowledge of the soil erosion and sedimentation, and Geographic Information System (GIS) can help to assess and at least provide estimate information regarding the same problem for planning purposes.

The sediment yield is usually not available as a direct measurement but estimated by using a sediment delivery ratio (SDR). It is computed as the ratio of sediment yield at the watershed outlet (point of interest) to gross erosion in the entire watershed (Brady *et al*., 2001). SDR again can be computed based on several functions and factors such as drainage area, texture, nearness to the main stream, channel density, slope, length, land use/land cover, and rainfall-runoff factors (Ouyang and Bartholic, 1997). The site specific sediment delivery ratio based on slope, length and land use/land cover has been used. A large number of models exist for identifying non-point source pollution as well as in the design of the construction such as dams and reservoirs or water quality etc. In many cases, these models use the USLE (Wischmeier and Smith, 1978) or the revised version of the USLE (RUSLE, Renard *et al.*, 1997) to model erosion on hillslopes in conjunction with sediment delivery ratios to determine the sediment delivered from the hill slope to water bodies.

1.2 Purpose of the study

Generally, when we think of doing any kind of work we do, we always keep humans at the heart of the work. Which means by assessing the soil erosion problem with GIS and letting the concerned authorities know about the problem for decision making and implementation purposes, we try to reduce the negative implications and try to improve the quality of life our native human beings. Similarly, while carrying out this research studies, the main purpose is to make the environment and agriculture sustainable and improve the quality of life of the people in the near future. The study was focused on methodological study on understanding the usage of geo-informatics technology on estimating soil loss using USLE. The main specific objectives were:

1. To classify the land use and land cover maps for two periods.
2. To estimate the soil loss based on two periods using USLE model.

3. To describe the effect of land use and land cover changes on soil loss.
4. To identify the severity of soil loss distribution.

1.3 Basic assumption

It is assumed that topographic, erosivity, erodibility and land use conditions within each cell are uniform.

1.4 Scope and limitations of the study

The study provides an assessment in understanding a kind of land use pattern in two periods of time in the study area and when integrated with other factors, it determines soil loss; in which would help to evaluate the change of erosion rate for two periods of time. Thus, it provides information on the importance of land cover/land use and land management activities for the natural soil resources conservationists in further enhancing the productivity of the agricultural soil.

The study has optimized utilizing all the available spatial data and information, other factors and ancillary datasets required to assess and represent the best estimation of soil loss in the study area. Despite many advantages of integration of RS and GIS with USLE for assessing erosional soil loss, the present study also had some limitations (Breiby, 2001). Some of which are as follows:

1. Scale difference of base data for deriving soil erosion factors;
2. Rainfall stations were not uniformly distributed in the study area;
3. Generalization of land use/cover classes into major classes only based on the capability of remotely sensed data.
4. Limitations in mathematical calculations due to inheriting errors of each input dataset.

CHAPTER II

LITERATURE REVIEW

2.1 Concept of soil erosion

Erosion is a natural geomorphic process occurring continually over the earth's surface (Saha, 2004). However, the acceleration of this process through anthropogenic perturbations and poor land use can have severe impacts on soil and environmental quality. Poor land use practices include deforestation, overgrazing, unmanaged construction activity and road or trail building. However, improved land use practices can limit erosion, using techniques like terrace-building and tree planting etc. Excessive erosion does cause problems, such as receiving water sedimentation, ecosystem damage and outright loss of soil, which could result in partial or complete loss of its productive capacity.

Soil erosion is a three-stage process, which includes:

(1) Detachment,

(2) Transport, and

(3) Deposition of soil.

Soil erosion begins with detachment, which is caused by break down of aggregates by raindrop impact, sheering or drag force of water. Detached particles are then transported and deposited when the velocity of water decreases by the effect of slope or ground cover.

The rate of erosion tenses on many factors, including the amount and intensity of precipitation, the texture of the soil, the gradient of the slope, ground cover from vegetation, rocks, land use, and possibility of erosion from speed of a stream. The first factor, rain, is the main agent for erosion, but the degree of erosion is governed by other factors too. The first three factors can remain fairly constant over time. In general, given the same kind of vegetative cover, we expect areas with high-intensity precipitation, sandy or silty soils and steep slopes to be the most erosive. Soils with a greater proportion of clay that receive less intense precipitation and are on gentle slopes tend to erode less. The factor that is most subject to change is the amount and type of ground cover. In an undisturbed forest, the mineral soil is protected by a litter layer and an organic layer. These two layers protect the soil by absorbing the impact of rain drops. These layers and the under-laying soil in a forest are porous and highly permeable to rainfall. Typically only the most severe rainfall events will lead to overland flow in a forest.

Soil is lost both by natural and anthropogenic perturbations (Hanson, 2003). Natural erosion occurs when soil is in its natural environment, surrounded by its natural vegetation. This type of erosion has been taking place over millions of years. While existing soil is gradually lost, new soils can be formed through the slow weathering of parent rock material, and from soil particles moved in by air and water. Under normal climate conditions, and with stable ground cover, soil losses from this type of soil erosion often can balance out, or even be less than, the rate of soil production. A classic example of natural erosion is the Grand Canyon.

Anthropogenic accelerated erosion is caused by the activities of human beings. By removing surface vegetation and plant residue cover, the soil becomes more vulnerable to removal by wind or water. Agricultural production can contribute to accelerated erosion, as can forest harvesting, surface mining, housing and construction, and urban highway construction, all of which eliminate stable plant cover. Heavy grazing can reduce vegetation enough to increase erosion. Changes in the kind of vegetation in an area can also affect erosion rates. Different kinds of vegetation lead to different infiltration rates of rain into the soil. Forested areas have higher infiltration rates, so precipitation will result in less surface runoff, which erodes. Instead much of the water will go in subsurface flows, which are generally less erosive. Leaf litter and low shrubs are an important part of the high infiltration rates of forested systems, the removal of which can increase erosion rates. Leaf litter also shelters the soil from the impact of falling raindrops, which is a significant agent of erosion. Vegetation can also change the speed of surface runoff flows, so grasses and shrubs can also be instrumental in this aspect.

One of the main causes of erosive soil loss is the result of slash and burn treatment of tropical forest. When the total ground surface is stripped of vegetation and then seared of all living organisms, the upper soils are vulnerable to both wind and water erosion. Severe fires can lead to significantly increased erosion if followed by heavy rainfall. In the case of construction or road building when the litter layer is removed, the susceptibility of the soil to erosion is greatly increased.

Particularly, in spatial modeling of soil loss with USLE, causes can be grouped into four major environmental and agricultural parameters that are taken into consideration as explained below.

2.2 Factors affecting soil erosion

Factors can be generally grouped in to four primary types (Costick, 1996). Each factor is as explained:

2.2.1 Climatic factor: rainfall

Rain is a type of precipitation, a result of the condensation of atmospheric water vapor that is available on the earth's surface. Soil loss is closely related to rainfall through the combined effect of detachment by raindrops striking the surface and by runoff (Mkhonta, 2000). The ability of rainfall to cause erosion depends on characteristics such as rainfall energy and rainfall intensity. The amount of rainfall governs the overall water balance and the relative proportion that becomes runoff (Hagos, 1998).

Erosion relies on two types of rainfall events; the short-lived intense storm, where the infiltration capacity of the soil is exceeded and the prolonged storm of low intensity, which saturates the soil before runoff really begins. Also the drop size distribution and its kinetic energy affect the splash detachment of the soil particles. Big raindrops have high erosive power.

2.2.2 Soil texture

Soil texture is a soil property used to describe the relative proportion of different grain sizes of mineral particles in a soil. Particles are grouped according to their size into what are called soil separates (clay, silt, and sand). Nowadays, they are broadly grouped into three classes based on the particle size by USDA as:

Clay: less than 0.002 mm

Silt: 0.002 to 0.05 mm (silt + very fine sand)

Sand: 0.05 to 2 mm (fine sand + very coarse sand)

The effect of soil on erosion is reflected through the resistance of soil to both detachment and transport, defined through the soil erodibility factor (Morgan, 1995). The particle size plays an important role in erosion process. Larger particles are more resistant to transportation as greater force is required to move. However, soil with particle size less than 0.06 mm, erodiblity is limited due to cohesiveness properties. The particles that are less resistant to erosion are therefore silt and fine sand (Petter, 1992). The soil texture also plays a greater role on infiltration capacity, which depends on pore size and pore stability. Therefore clay soils have low infiltration capacity and produce more overland flow than soil consisting of coarser material with higher infiltration capacity (Petter, 1992).

The level of erosion will differ with different soil series. A soil series is a naturally occurring entity on the landscape. In Thailand, soil series as established by the LDD are soils that are grouped together because of their similar pedo-genesis, soil chemistry, and physical properties. These result in soils which perform similarly for land use purposes. A soil series name generally is derived from a town or landmark in or near the area where the soil series was first recognized at the areas of at least 25 sq. km.

2.2.3 Topography

Mass movement is the down-slope movement of rock and sediments, mainly due to the force of gravity and depends upon the steepness of slope. USLE prediction is best found to be more representative in a gentle watershed area, where the action of gravity is not much. It has been demonstrated that increase in slope length and slope steepness can produce higher overland flow velocities and correspondingly higher erosion (Haan *et al.*, 1994). Moreover, gross soil loss is considerably more sensitive to changes in slope steepness than to changes in slope length (McCool *et al.*, 1987).

2.2.4 Land use (vegetation cover) and agricultural support practices

Here in this study, the term vegetation will mean the land cover types of the study area. The agricultural land use/cover and management factor reflects the effect of cropping and support practices on soil erosion rates (Renard *et al.*, 1997). As climatic erosivity and soil erodibility factors are essentially uncontrollable; land use support practices are the deciding factors in determining the extent of soil erosion, and erosion induced degradation. On a given plot of agricultural land, erosion can vary from acute to almost nil depending on the cropping system. Vegetative cover plays a crucial role as erosion is significantly reduced under thick cover. In some cases a vicious cycle can arise, where erosion reduces soil productivity, resulting in less crop cover and hence more erosion and so on (Hudson, 1971). In other words, generally poor crop cover means that poorer farms may suffer from more severe erosion on their land, resulting in less future production and even more erosion.

As the protective canopy of the land cover increases, the erosion hazard decreases (Mkhonta, 2000). It protects the soil against the action of raindrops, increases the power of infiltration and also reduces the speed of surface runoff. As long as the land cover is unbroken, despite great erosive rainfall or steep slope, the runoff will still be maintained small. The surface runoff also depends on type of vegetation cover and density. Land with good cover will always experience low amount of erosion.

In agriculture, a terrace is a leveled section of a hilly cultivated area, designed as a method of soil conservation to slow or prevent the rapid surface runoff of irrigation water. Often such land is formed into multiple terraces, giving a stepped appearance.

Soil cover in the form of crop plants, cover crops, mulches, or residues can protect soils from wind and water erosion, enhance water infiltration, and help maintain or increase organic matter. Practices that maintain soil cover include: minimum tillage, cover cropping, managed grazing, contour planting, strip cropping, crop rotation, control structures and diversions to protect soils from water erosion by decreasing the effective slope length along a field.

2.3 Mathematic models and soil erosion models

The problem of soil erosion is major issue on agriculture productivity and yet the numbers of contributing variables make the estimation more difficult and complex. Even though there are several predicting models available, all are objective oriented, as no single prediction model can suffice all needs. Therefore, for assessment of soil erosion, long-term inputs are required for estimating long-term annual average soil loss.

Several models were developed and numerous are in the process of development and some of which are CREAMS, WEPP, SLEMSA, EUROSEM, GUESS, USLE, RUSLE, RMMF and MUSLE etc…Most have been developed for agricultural areas and are designed to compare predicted annual rates of soil loss from broad areas under various cropland and rangeland management techniques. All these mathematical models can be differentiated either deterministic or stochastic model, based on which different models were classified as shown in the Figure 2-1.

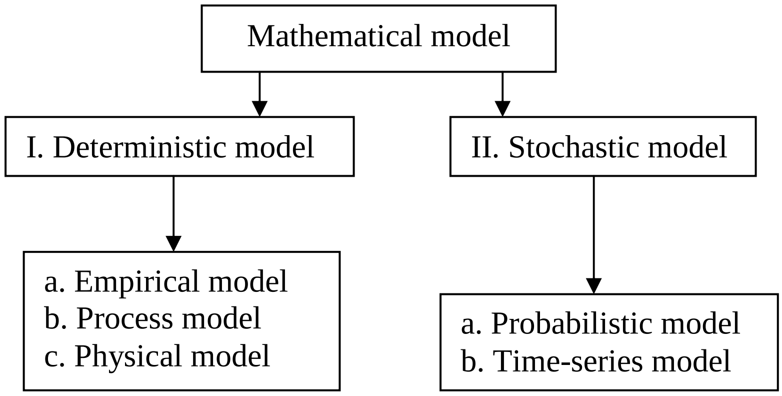

Figure 2-1 Different mathematical models (LDD, 2004)

I. Deterministic Model: A model for which there is only one possible answer for a given set of inputs.

a. **Empirical Model**: a simplified representation of a system or phenomenon that is based on experience or experimentation. Examples are SLEMSA, MUSLE, USLE, RUSLE etc...

b. **Process Model**: It can be either detailed or simplified mathematical models, which are based on the representation of basic physiological processes. USLE can be an example.

c. **Physical Model**: It incorporates the laws of conservation of mass and energy (Petter, 1992),where energy can change form but total energy remains same. They are firmly based on the understanding of the physics of erosion processes. Examples are CREAMS, ANSWERS, EUROSEM, and AGNPS etc...These models were supposed to explain dynamics of detachment, transport and deposition not like USLE or RUSLE.

II. Stochastic Model: A model that recognizes that there could be a range of possible outcomes for a given set of inputs, and expresses the likelihood of each one happening as a probability. Eg: patients not responding to the same medication by physician.

a. **Probabilistic Model**: A model that assigns a likelihood to events or data within a population, as expressed by a ranked numerical value or an estimate of best case, worst case or most likely. As an example of deterministic versus probabilistic models, consider the past and the future: Nothing we can do can change the past, but everything we do influences and changes the future, although the future has an element of uncertainty.

b. **Time-series Model**: a time series is a sequence of data points, measured typically at successive times, spaced at (often uniform) time intervals. Time series analysis comprises methods that attempt to understand such time series, often either to understand the underlying context of the data points (where did they come from? what generated them?) or to make predictions.

Much of the research on erosion rates is directed towards supporting or fitting these competing models. Since then many changes were proposed, but all models revolve on a same concept of rainfall erosivity, soil erodibility, slope length, steepness, land cover and management factors taken directly proportional to the rate of annual soil erosion (Sohan and Lal, 2001).

2.4 Related literatures in spatial modeling of soil erosion

Many studies and researches on soil erosion modeling using different erosion models have been carried out throughout the world. The major contributions were accredited to US government for their unwavering and undying continuous research and development, which has come through a long way from 1940s regarding soil loss assessments. Here at this juncture, the studies carried out in Thailand are discussed briefly. The erosion studies in Thailand dates back from early 1990s.

Mongkolsawat, Thirangoon and Sriwongsa (1994) carried soil erosion mapping using USLE and GIS in Huai Sua Ten watersheds covering part of Khon Kaen and Udon Thani provinces. High erosion classes concentrated in areas where land is used for field crops with no conservation practice. The resultant soil erosion map, produced using GIS, was checked against existing soil erosion maps and data of field surveys. It was found to be satisfactory. The study confirms that the use of GIS and remotely sensed data can greatly enhance spatial modeling of soil erosion.

Shrestha, Eiumonoh and Baimoung (1996) carried out soil erosion assessment using RS/GIS and USLE in Uthai Thani province for policy implementations. The study has found that the upland area under sugarcane cultivation is most severe prone areas. The study recommends the need of long-range conservation measures to address the problem of soil degradation.

Land Development Department (2000) has carried out the soil erosion assessment throughout whole Thailand using RS/GIS with the original USLE model. The study has found the distribution of soil loss in whole Thailand. The soil loss was found to be more in the areas where there are no vegetation covers and steepy areas.

Chandraprabha (2002) has carried out the implication studies of land use change on soil erosion hazards in Lam Phra Phloeng watershed using the USLE model with GIS for two years 1990 and 2000 respectively. The study has concluded that the soil loss risk is huge in the area.

Yazidhi (2003) utilized RS/GIS with RUSLE and RMMF models to study of soil erosion modeling in Lom Kao-Phetchabun, Thailand. He has found that the soil loss from RUSLE model was more than that of RMMF model and recommended RUSLE as a better choice.

Cho and Zoebisch (2003) studied the land cover changes characteristics and the driving forces in the Upper Lam Phloeng watershed over the last 45 years. It basically discusses the conversion of forest land cover to present agricultural land uses. They have found that the farmers in the area have the perception of decline in soil fertility rate and the need for more fertilizers to produce good yield.

Land Development Department (2004) has also recently carried out the soil erosion assessment throughout whole Thailand using RS/GIS with the Revised Morgan Morgan and Finney model. The applicability of the RMMF was also found to be viable although the data input require is more complex in nature as compared to USLE.

Paiboonsak *et al*. (2004) have carried out the spatial modeling of soil erosion assessment in Upper Chi Basin of Northeastern Thailand using RS/GIS and USLE. This study provides the very severe soil loss cover an area of about 5.7% for which, the total soil loss exceeds 45% of the watershed area. Soil conservation measures were placed emphasis on the very severe and severe soil loss.

Mongkolsawat, Paiboonsak and Chanket (2006) have carried out study on soil erosion in northeast Thailand using GIS and USLE. The study indicated the soil loss severity (7.94%) was in the mountainous areas with steep slopes with degraded forests.

Lorsirirat (2007) of Royal Irrigation Department has carried study on Effect of Forest Cover Change on Sedimentation in Lam Phra Phloeng Reservoir, Northeastern Thailand. The study was mainly aimed to predict the lifespan of the reservoir where its capacity has been reduced by the sedimentation process from 1970 to 2000. He has described the impact of loss of forest cover in erosion process and he concluded the agricultural lands were prone to erosional loss of soil.

Wahid, S. M. and Babel, M. S. (2008) have done a case study in Lam Phra Phloeng watershed for evaluating landscape predictors with reference to watershed hydrology. The result found that while the tenure per se appears not to affect hydrology, the effect of land use, tenure and altitude have contributed for controlling runoff in the watershed.

It can be deducted from the above literatures that land is an indispensable resource for the most essential human activities: it provides the basis for agriculture and forest production, water catchment, recreation, and settlement. The range of uses that can be made of land is limited by environmental factors including climate, topography and soil characteristics, and is to a large extent determined by demographic, socio-economic, cultural and political factors such as population density, land tenure, markets, institutions, and agricultural policies (FAO, 2007). That is why; often land degradation needs to be assessed on a frequent basis as Landis a basic and finite resource and we are degrading large amounts of it (Genske, 2007).

CHAPTER III

STUDY AREA

3.1 Location and administration

Lam Phra Phloeng, a typical agricultural watershed has been selected for the study. The area stretches approximately from 101° 28′ 57″ to 101° 54′ 06″ towards east and 14° 18′ 26″ to 14° 38′ 33″ North in WGS_84 coordinate system with total acreage of 782.31 Sq. km. It falls under the jurisdiction of about three main districts of Wang Nam Khieo, Pak Chong, and Pak Thong Chai. Other neighboring districts are also depicted as shown in Figure 3-1.

3.2 Topography

The study area is characterized by an upland topography with undulating slope and flat areas. The area is bounded by Pha Khao Phu Luang National Reserve Forest in the north-east and Khao Yai National Park in the south-west. The elevation ranges approximately from 175 m to 1,300 m above Mean sea Level (MSL) as shown in Figure 3-2. The middle part of the study area, which is of gentle slope nature where major part of land is used for agriculture is of major concern of erosion problem.

3.3 Climate, rainfall and temperature

The area experiences three seasons in a year viz. cool dry, hot dry and rainy season. The cool dry season is influenced by the northeast monsoon carrying cold

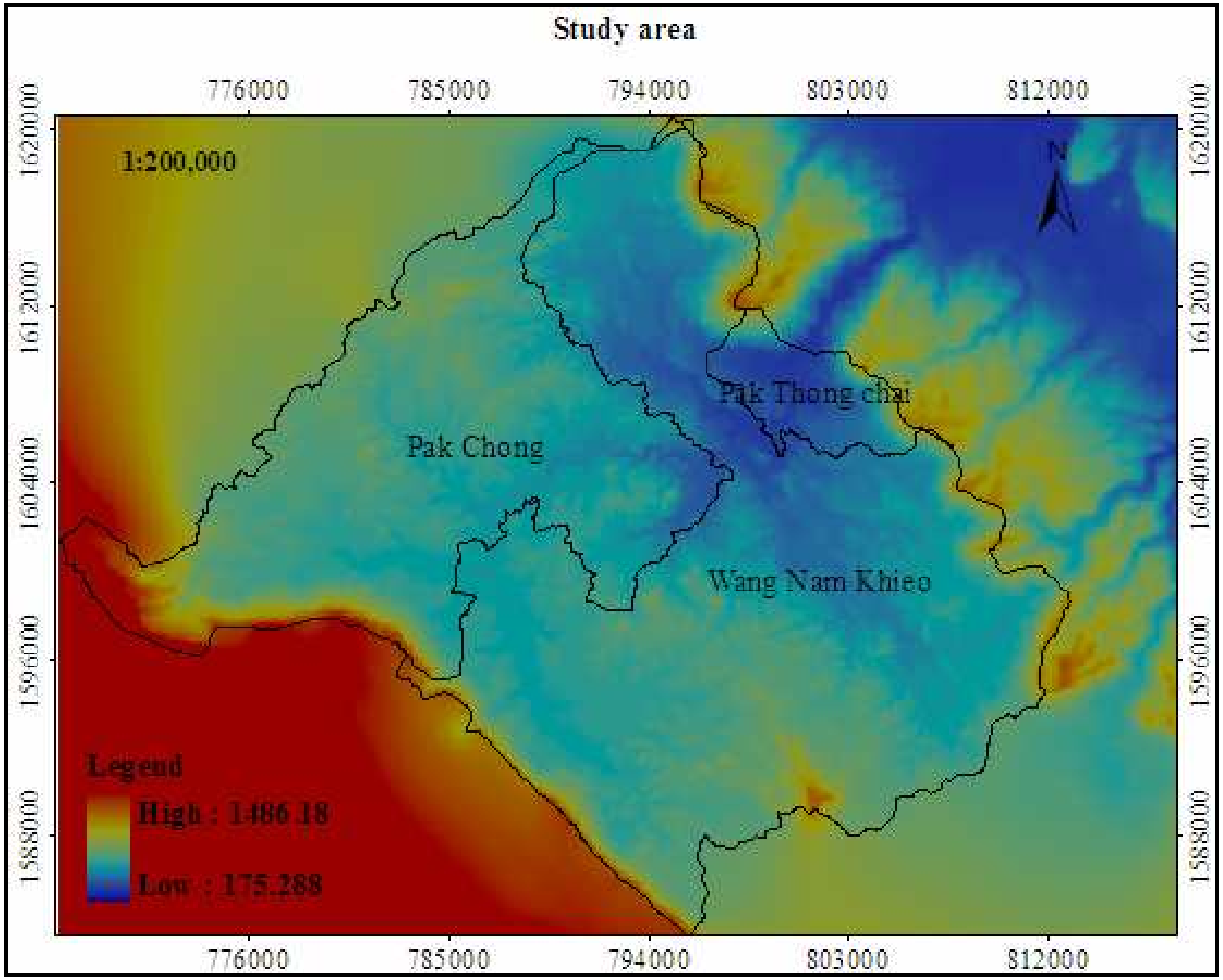

Figure 3-1 Study area and its jurisdiction

winds from Siberia from mid-October to mid-February. The hot dry extends from mid-February to mid-May. The rainy season extends from mid-may to mid-October which is affected by southwest monsoons and cyclones from South China Sea with an average of 1,000 mm annual rainfall. The mean monthly maximum temperature in the study area ranges from 27°C in December to 37°C in June and minimum temperature from 14°C in December to 24°C in June (Chandraprabha, 2002).

In 2003, the total population of this watershed was 29152, where more than 80% were engaged in agricultural activities. The average family income of the people in the watershed was about 50,000 Thai Baht annually (Wahid, S. M. and Babel, M. S., 2008).

3.4 Land use and land cover

Maize is the dominant crop grown in the upper area and some areas are also allotted for planting cassava, sugarcane and mungbean. In areas neighboring to Koa Yai National Park, the dense evergreen forest coverage were quite good as it is declared as the "protected buffer zone" in from 1980s. Since then the forest natural re-growth was ever increasing and was well maintained. Still then the most part of the forest cover have been encroached for the agriculture purposes.

Similarly, mango orchard accounts majority amongst the fruits, but there are also small plantations like custard apples, tamarind, papaya and jackfruit. Vegetables like eggplant, chili, cabbage and other varieties are also grown. The water bodies and village/urban areas also account for some percentage in the area although there is no significant coverage in the study area.

3.5 Soil and geology

3.5.1 Soil group and series in study area

More than 300 series of soil have been identified in whole Thailand. Soil series with similar characteristics have been grouped into 62 soil groups by LDD (http://www.ldd.go.th). The 11 soil groups found in the study area have been briefly described with other examples too. About 14 soil series found in the study area are marked in italic.

Group No. 22: This group of soils is of poorly drained; coarse-textured that occur on low-lying terrain. They are very low fertility. Soils in this group are Num Krachai (Ni), Sansai (Sai) and *Sri Thon (St)* series.

Group No. 29: This group of soils is well drained and deep fine-textured that occupies erosional surfaces and alluvial terraces or fans in dry areas of the country. Soil fertility is moderately low. Soils in this group are *Ban Chong (Bg),* Chiang Khong (Cg), Choke Chai (Ci), Mae Taeng (Mt), Nong Mot (Nm), *Pak Chong (Pc)* and Sung Nern (Sn) series.

Group No. 31: This group of soils is well drained, deep and fine-textured derived from fine-grained clastic rocks. Weathered bed rock commonly occurs at the depth of 125 - 175 cm from soil surface. Soil fertility is moderately low. Soils in this group are Loei (Lo) and *Wang Hai (Wi)* series.

Group No. 40: This group of soils is well-drained, deep and coarse-textured that develops from alluvial deposits or wash materials on the uplands of alluvial terraces, fans or erosional surface in the areas of low precipitation. They are low fertility. Soils in this group are Chakra Rat (Ckr), Chum Puang (Cpg), Hup Krapong (Hg), Huay Thalang (Ht), San Patong (Sp), *Pak Thong Chai (Ptc*) and Yang Talat (Yl) series.

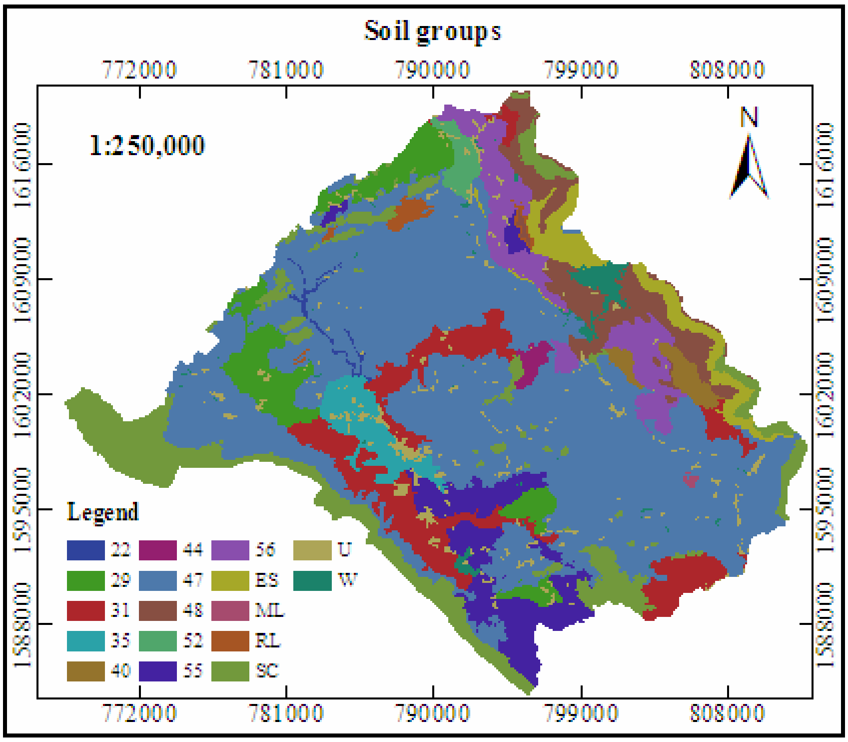

Figure 3-2 Soil groups found in the study area

Group No. 44: This group of soils is deep sandy, somewhat excessively drained that occur on alluvial terraces, fans and wash surface. Its parent material is closely related to coarse grained clastic rocks and coarse grained igneous rocks in areas of low precipitation. Soil fertility is very low. Soils in this group are *Chan Tuk (Cu)*, Dan Khun Thot (Dk) and Nam Phong (Ng) series.

Group No. 47: This group of soils is shallow to fine-grained bed rock. It occupies erosional surface, hills and mountains in low precipitation areas. Soils in this group are *Li (li)*, *Muak Lek (Ml)*, Sop Prap (So), Nakhon Sawan (Ns), Pong Namron (Pon) and Tali (Tl) series.

Group No. 48: This group of soils is shallow to coarse-grained bed rock. They commonly occur on erosional surface, hills and mountains. Soils in this group are

Mae Rim (Mr), Nam Chun (Ncu), Payao (Pao), *Wangnam Khieo (Wk)* and Tayang (Ty) series.

Group No. 52: This group includes all soils that are shallow calcareous layer in low precipitation areas. Dark surface layer of alkaline that is friable in moist condition. Fertility is high. Soils in this group are Bung Chanang (Bng) and *Takhli (Tk)* series.

Group No. 55: This group of soils is moderately deep, fine-textured and well drained that developed from clastic rocks in low precipitation areas. Will be cracked in dry season. Soil fertility is moderate. Soils in this group are Chatturat (Ct) and *Wang Saphung (Ws)* series.

Group No. 56: This group of soils is similar to soil group No. 55. The main difference is coarser-textured and coarse, grained clastic weathered-rock layer i.e. sandstone and equivalent rocks that are found at 50 - 100 cm depth. Lad Ya (Ly), Pu Sana (Ps), *Bo Thai (Bo) and Phon Ngarm (Png)* series.

Group No. 62: This group of soils includes all steep lands with more than 35 percent slopes (SC: slope complex). Soil qualities vary as geological setting of the areas. This group of soils should restrict their uses to woodland, watershed protection and wildlife conservation.

3.5.2 Geological formations in study area

The unpublished geological map prepared by Department of Mineral Resources (DMR) has about 13 geological formations in the study area (Figure 3-4). The brief description of rock types and symbol of each formation is as follows:

Jpk (Phu Kradung): Siltstone, greenish gray to yellowish brown calcareous and micaceous: Sandstone, grayish brown to greenish gray, fine grained, thin to thick-bedded, cross-bedding; locally basal conglomerate.

Jpw (Phra Wihan): Sandstone thick-bedded, quartz, quartzite; white, brown and yellowish- brown; claystone, purplish-red siltstone and whitish-gray.

P (Unnamed): Phyllitic shale, siltstone, thin bedded, light brown, brown, brown-gray and intercalated with hornfels and quartzite, thin bedded, gray, gray chert locally contact metamorphosed.

P2 (Unnamed): Limestone, light-gray to gray, laminated to thick-bedded, interbedded with chert bedded and lenses; argillaceous limestone, gray to pinkish brown interbedded in upper part, fusulinids, smaller foroms, crinoid stems, algaes and gastropods.

P3 (Unnamed): Shale , greenish gray to dark greenish gray, laminated, dark limestone dark gray limestone lense intercalated in lower part ; partialy tuffaceous limestone and pebbly shale ; locally spotted phyllitic shale, phyllitic shale, slaty shale and schist.

PTRan (Andesite): Andesite and associated volcanic rocks include andesite porphyry or equigranular and pyroclastic volcanic rocks such as tuff, andesitic breccia and agglomerate, agglomerate, rhyolite may present in small amount.

PTRrh (Rhyolitic): Rhyolite and associated rocks, purple, purple-gray and greenish-gray composed of rhyolite porphyry and fine grained equigranular, and pyroclastic rocks of mainly tuff, most rocks show well developed flow foliation, rhyolitic tuff is always present.

Qa (Quaternary): Alluvial deposit, gravel, sand, slit and clay.

TRgr (Granite): Intrusive igneous rock: granodiorite, diorite and monzodiorite.

Trgr1 (Granite1): Hornblende granite, hornblende-biotite adamellite, hornblende diorite, hornblende gabbro and hornblendite gray to black medium to coarse grained equigranular texture.

TRgr2 (Granite2): Biotite granite, biotite adamellite and biotite-mascovite-tourmaline

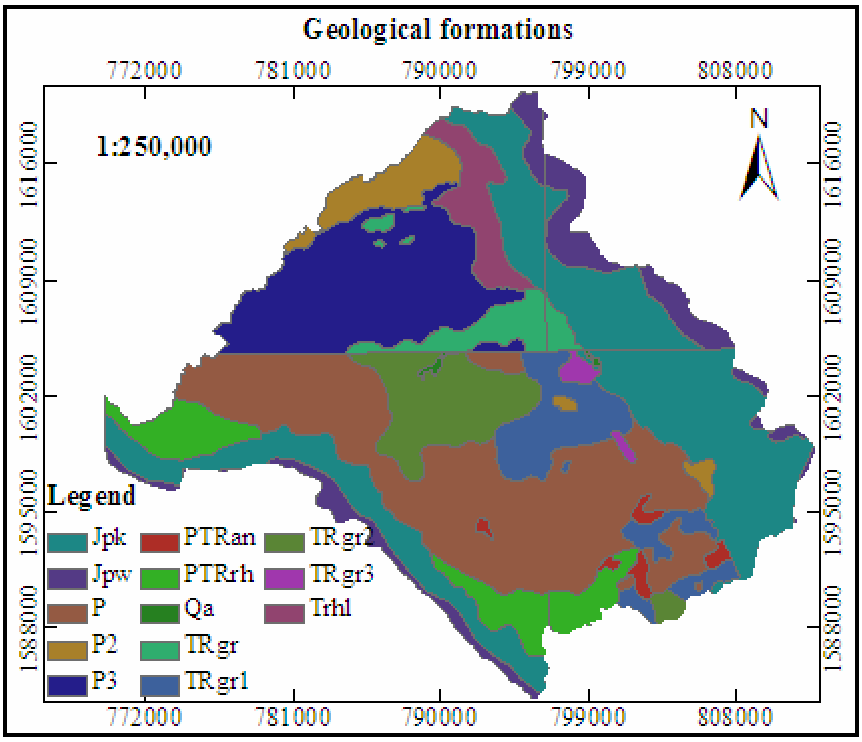

Figure 3-3 Geologic formations of the study area

granite, gray to light gray medium-coarse grained, equigranular and porphyritic texture.

TRgr3 (Granite3): Biotite-hornblende granite, fine-medium grained equigrnular texture.

Trhl (Huai Hin Lat): Shale, dark greenish gray, interbedded with mudstone, greenish gray, calcareous, thin to thick - bedded, argillaceous limestone, gray to yellowish brown; basal conglomeratic limestone.

3.6 Transportation and others

The study area seemed to have good connectivity of road network coverage as almost all the villages in the area are linked with motorable roads facility. Although there is no network coverage for mobile phone in some villages, rural electricity and rural water supply scheme in most rural parts of the area is also made available.

3.7 Data and equipment

For carrying out this research work, number of data and other equipment resources besides computer hardware and softwares have been used. Data were grouped into RS and GIS data and equipment into hardware and software. An inventory of RS/GIS data and equipment resources already obtained are shown in the Table 3-1.

Table 3-1 Data and Equipment

Data and Equipment		**Scale/ Cell Size**	**Year**	**Remarks**
I) RS/GIS Data Types				
a) Primary Datasets	Rainfall data	N/A	2000/ 2007	TMD[1]
	Landsat TM	30X30 m	2000/ 2008	GISTDA[2]
	Digital contour	1:50000	2000	RTSD[3]
	Digital soil map	1:25000	2004	LDD
	Geology map	1: 50000	2008	DMR[4]
b) Secondary Datasets	Topo. map	1:50000	2000	RTSD
	Land use map	1:25000	2007	LDD
	Orthophoto	1:4000	2000	LDD
II) Equipment				
Hardware and Software	GPS	N/A	N/A	RS Lab.
	Compaq notebook	N/A	N/A	Personal
	ArcGIS 9	N/A	N/A	RS Lab.
	ArcPad 6.0.2	N/A	N/A	RS Lab.
	Ilwis 3.4	N/A	N/A	Open Source
	Erdas Imagine 8.7	N/A	N/A	RS Lab.

[1]Thai Meteorological Department
[2]Geo-Informatics and Space Technology Development Agency
[3]Royal Thai Survey Department
[4]Department of Mineral Resources

CHAPTER IV

METHODOLOGY AND PROCESSING

4.1 Modeling erosion by USLE

The Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978) is the most frequently used empirical soil erosion model worldwide. The USLE model has advantages because its data requirements are not too complex or unattainable, it is relatively easy to understand, and it is compatible with GIS (Millward and Mersey, 1999). When used in conjunction with raster-based GIS, the USLE model can isolate locations of erosion on a cell by cell basis, determine the role of individual variables on the rate of erosion, and identify the spatial patterns of soil loss within a watershed (Millward and Mersey, 1999). The USLE is written as:

$$\mathbf{A} = \mathbf{R} \times \mathbf{K} \times \mathbf{L} \times \mathbf{S} \times \mathbf{C} \times \mathbf{P} \quad (1)$$

Where,

A is the computed spatial average soil loss and temporal average soil loss in t/ha/year;

R is the rainfall–runoff erosivity factor in MJ mm/ha/h per year;

K is the soil erodibility factor- for a specified soil as measured on a standard plot, which is defined as a 22.13 m length of uniform 9% slope in continuous clean-tilled fallow in (t h/MJ mm); L is the slope length factor –

the ratio of soil loss from the field slope length to soil loss from a 22.13 m length under identical conditions.

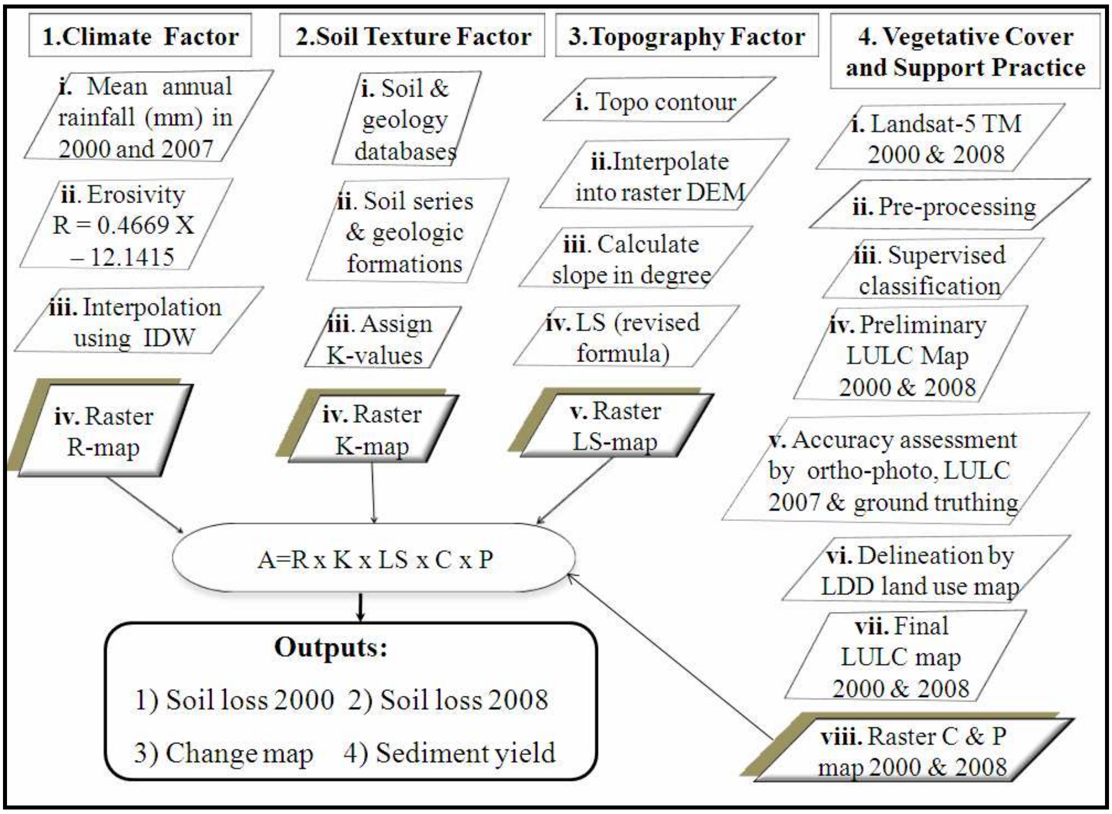

Figure 4-1 Integration of factors for assessing erosion

S is the slope steepness factor-the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions.

C is the cover and management factor- the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.

P is the conservation support-practices factor- the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to soil loss with straight-row farming up and down the slope.

The L, S, C, and P are dimensionless. The general schematic diagram of procedures followed and integration of input sources, factors and expected outputs while assessing soil erosion is shown in the Figure 4-1 in more detail.

4.2 Rainfall-runoff erosive factor, R

4.2.1 Concept

Climate data like rainfall is prerequisite for modeling the soil erosion. However, the data like rain storm duration necessary to evaluate the erosive power of rainfall was not available in developing countries like Thailand. Hence regression equation developed like shown below was used as a last resort. The digital rainfall data were obtained from Nakhon Ratchasima and Chonburi Hydrology and Water Management Office websites of Royal Irrigation Department (RID).

4.2.2 Data processing

The schematic diagram of the procedure adopted during the data preparation and processing is as depicted below in the Figure 4-2. The monthly rainfalls have been reduced to annual mean rainfall in millimeters for the erosivity at each common 10 stations. Since there were less number of stations in the study area, the rainfall from the neighbouring stations were also used. For R-factor, equation defined by Land Development Department (LDD, 2000) for Northeastern part of Thailand has been taken as best choice for this study. The equation is written as:

$$R = 0.4669\ X - 12.1415 \qquad (2)$$

Where,

R = Rainfall-runoff erosivity factor in MJ mm/ha/h per year and

X = Mean Annual Rainfall (mm)

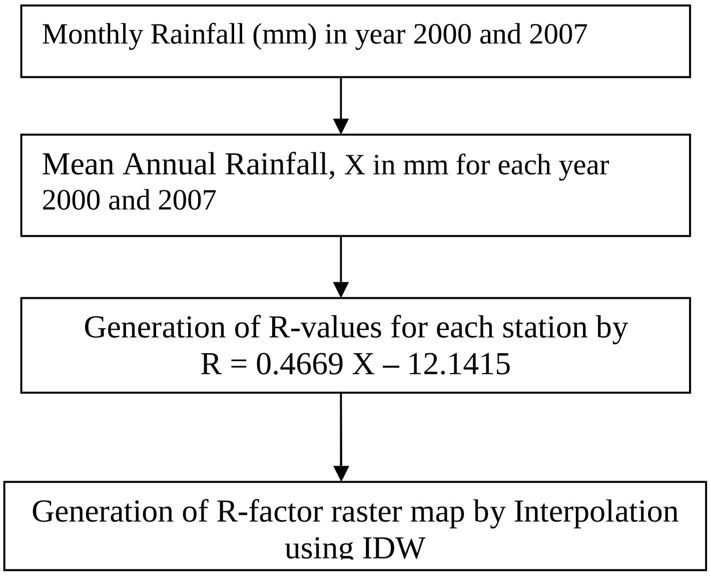

Figure 4-2 Procedures adopted for obtaining R factor

The Inverse Distance Weighted (Appendix A) interpolation has been employed to establish the spatial layer of the R-factor. Table 4-1 shows the mean annual rainfall and derived rainfall-runoff erosive values in year 2000 and 2007 respectively.

Table 4-1 Mean annual rainfall and derived rainfall-runoff erosive values (R)

No	Station	Code	Mean annual rainfall in 2000	Rainfall-runoff erosive(R) in 2000	Mean annual rainfall in 2007	Rainfall-runoff erosive(R) in 2007
1	Pak Thong Chai	431005	932.20	423.10	862.7	390.65
2	Khoa Yai	431031	2,165.0	998.60	1,781.3	819.55
3	RM_145	25751	1,386.0	635.10	1,075.0	489.80
4	Huai krok De	25930	1,258.0	575.00	1,184.0	541.00
5	LPPDam (m33)	25511	1,115.2	508.55	1,283.0	587.00
6	RM_147	25781	1,106.0	504.00	1,043.0	475.00
7	RM_146	25771	1,530.0	702.30	1,207.0	551.50
8	Chokchai Farm4	25651	1,418.4	650.11	960.90	436.50
9	Ny1B	22341	2,083.5	960.64	1,904.0	877.00
10	Kgt 14	n.a	2,407.5	1,111.92	1,902.0	876.00

Figure 4-3 and Figure 4-4 depicts the rainfall-runoff erosivity, R-map generated using ArcGIS for year 2000 and 2007 respectively.

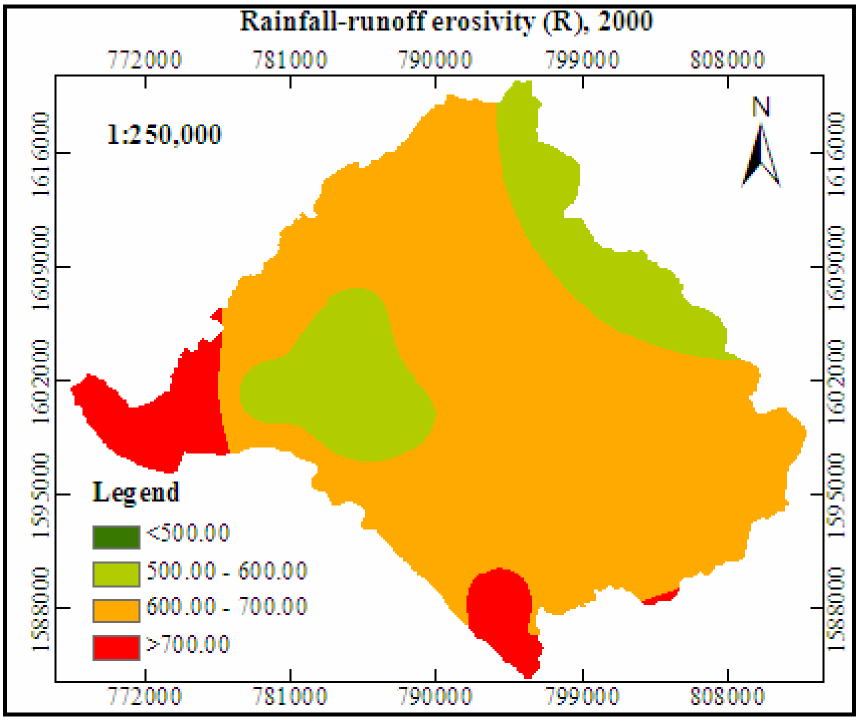

Figure 4-3 USLE R-grid map in year 2000

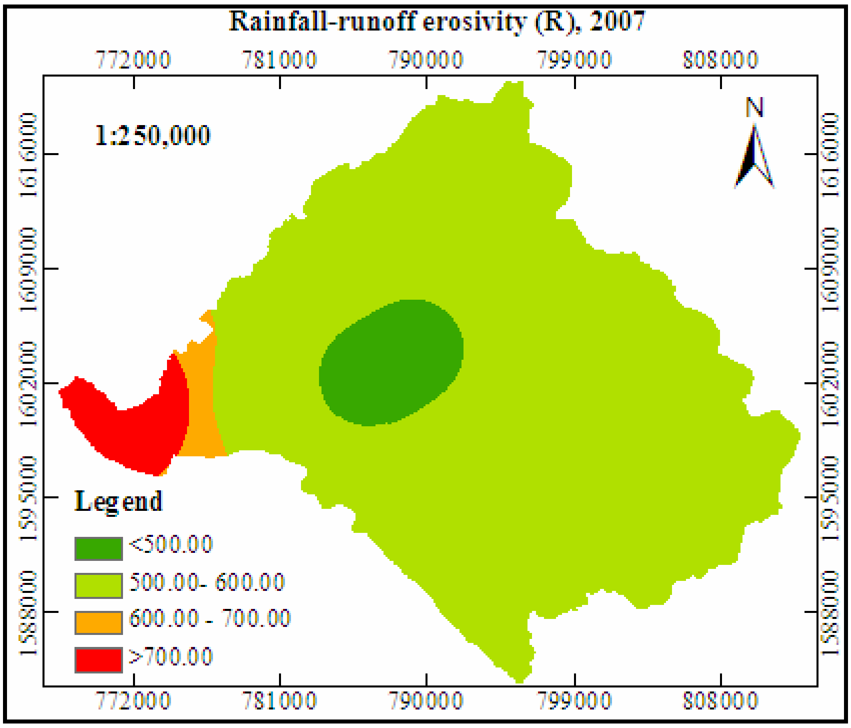

Figure 4-4 USLE R-grid map in year 2007

4.3 Soil erodibility factor, K

4.3.1 Concept

Soil erodibility is a complex property and is thought of as the ease with which soil is detached by splash during rainfall or by surface flow or both. Soil erodibility is related to the integrated effect of rainfall, runoff, and infiltration on soil loss and is commonly called the soil-erodibility factor, K (Renard *et al*., 1997). It is the long term soil and soil profile response to the erosive powers of rainstorms. The Experimental data have shown that K is not constant but varies with season, being highest in the spring with soil fluffing from freeze-thaw actions and lowest in mid-fall and winter following rainfall compaction or a frozen soil. Soils with higher value of erodibility factor, K, are more sensitive to erosion than soils with low value. K varies with the soil characteristics such as texture, structure, organic matter content, permeability and chemical properties etc...

4.3.2 Methodology and processing

Normally soil sampling were done in the field and laboratory tests for determining the percentages of fine sand, silt, clay and organic matter etc. After which the erodibility value for each soil texture can be estimated using the soil-erodibility nomograph method (Wischmeier and Smith, 1978; Renard *et al*., 1997). The nomograph (Appendix B) is also based on the equation, which can estimate K, where the silt fraction doesn't exceed 70%. It is shown below:

$$100K = (2.1*10^{-4}) * (12-OM) * M^{1.14} + 3.25(S-2) + 2.5*(P-3) / 7.59 \qquad (3)$$

Where,

OM = % of organic matter,

S = Soil structure class (1-4),

P = Soil permeability class (1-6),

M = (% silt + % very fine sand)*(100- %clay)

The soil permeability and structure codes are as shown in the Table 4-2 and Table 4-3.

Table 4-2 Soil permeability codes for texture types

USDA 12 Texture Types	Permeability code	Remarks
Clay, silty clay	6	Very slow
Silty clay loam, sand clay	5	Slow
Sandy clay loam, clay loam	4	Slow to moderate
Silt, silty loam, loam	3	Moderate
Loam sand, sandy loam	2	Moderate to Rapid
Sand	1	Rapid

Table 4-3 Soil structure code

Code	Structure	Size
1	Very fine granular	< 1 mm
2	Fine granular	1-2 mm
3	Medium/Coarse granular	2-10 mm
4	Blocky, platy or massive	

The texture type can be obtained using the USDA texture triangle (Appendix C) and brief descriptions of each texture type in Appendix D. LDD has also obtained the values in the study area through similar approach, which uses the twelve soil texture classifications that are similar to that of United States Department of Agriculture (USDA).

The digital soil map at 1 : 25,000 scale for 2004 originally obtained from LDD was used as base data. The factsheet of soil textures for each series were also obtained from LDD (2004). The textural values for K were based on published values of soil series and geological formations by LDD (2000) at 1 : 50,000 as shown in the Table 4-4 and Appendix E for more about geological rock types. For slope complex, like forests and high mountainous areas, k-values set for different geological formations were identified from geological map (2008) of DMR. For water bodies, rock land, man-made structures and urban human settlement polygons like schools and villages, a value of "0" was assigned as erosion is assumed to be null on these kinds of surfaces. The detail of the descriptions of the major rock types of each of the geological formations can be seen in Table 4-5.

Table 4-4 Soil erodibility (K) value based on soil series

Group	Soil Series	%Cl ay	%Sil t	%Sand	Texture	Erodibili
22	Sri Thon(St)	15.3	33.7	51	Loam	0.35
29	Pak Chong(Pc)	74.5	21.5	4	Clay	0.15
29	Ban Chong(Bg)	47.7	20.2	32.1	Clay	0.15
31	Wang Hai(Wi)	34.4	43	22.6	Clay loam	0.36
35	Dan Sai(Ds)	23.1	20.5	56.4	Sandy clay loam	0.20
40	Pak Thong Chai (Ptc)	-	-	-	Loamy sand	0.05
44	Chan Tuk(Cu)	6.2	7.8	86	Loamy sand	0.05
47	Muak Lek (ML)	58.3	26	15.7	Clay	0.15
	Li(Li)	43.5	46.4	10.1	Silty Clay	0.27
48	Wangnam Khieo (Wk)	-	-	-	Loamy sand	0.05
52	Takhli (Tk)	25.5	44.8	29.7	Loam	0.35
55	Wang Saphung(Ws)	40.4	27.3	32.3	Clay	0.15
56	Phon Ngarm(Png)	11.9	16.1	72	Sandy loam	0.26
	Bo Thai(Bo)	7.9	17.2	74.9	Sandy loam	0.26
62	Slope Complex(SC)*	n.a.	n.a.	n.a.	n.a.	(Table 4-5)
-	Urban	n.a.	n.a.	n.a.	n.a.	0
	Settlements(U)	n.a.	n.a.	n.a.	n.a.	0
-	Water bodies(W)	n.a.	n.a.	n.a.	n.a.	0
-	Rocky surfaces(RK)	n.a.	n.a.	n.a.	n.a.	0

Table 4-5 K values based on major rock types of each of the geological formations

Symbol	Formation	K	Major Rocks	Remarks
Jpw	Phra Wihan	0.29	Sedimentary and metamorphous	Most formations were unnamed as the database was not formally published.
Jpk	Phu Kradung	0.29	Sedimentary and metamorphous	
P	Unnamed	0.29	Sedimentary and metamorphous	
P2	Unnamed	0.29	Sedimentary and metamorphous	
P3	Unnamed	0.29	Sedimentary and metamorphous	
PTRan	Andesite	0.13	Igneous	
PTRrh	Rhyolitic	0.13	Igneous	
Qa	Quaternary	0.37	Alluvial deposit, gravel, sand, slit and clay.	
TRgr	Granite	0.13	Igneous	
TRgr1	Granite1	0.13	Igneous	
TRgr2	Granite2	0.13	Igneous	
TRgr3	Granite3	0.13	Igneous	
Trhl	Huai Hin Lat	0.29	Sedimentary and metamorphous	

The convert function from features to raster of spatial analyst has been used to convert the vector attribute k to raster at 30m cell size. It resulted to the generation of K-factor map (Figure 4-5).

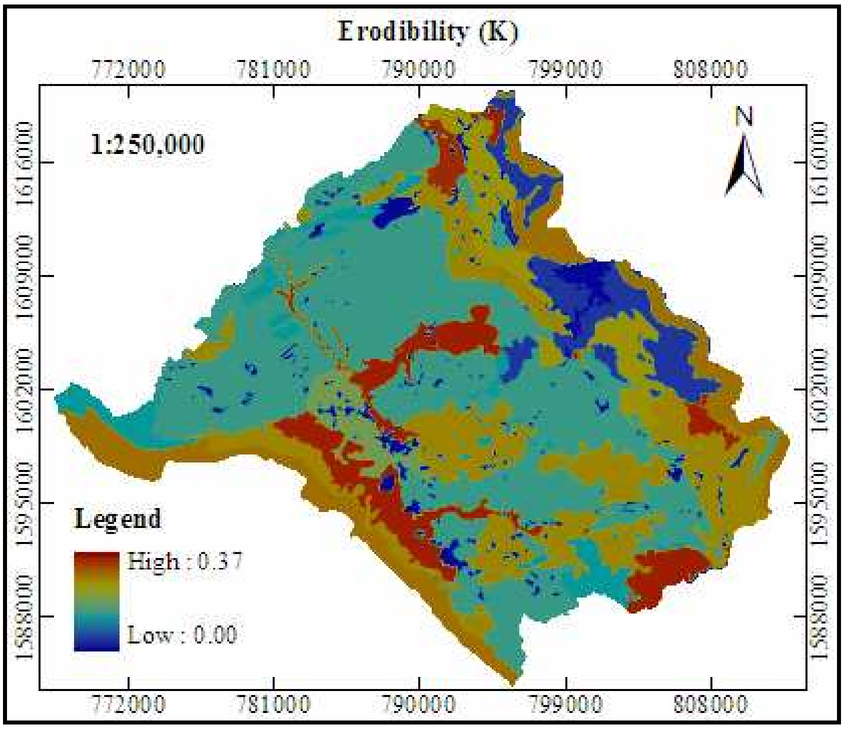

Figure 4-5 USLE K-grid map

4.4 Slope length and steepness factor, LS

4.4.1 Concept

Slope length has been broadly defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the flow is concentrated in a defined channel (Wischmeier and Smith, 1978). The specific effects of topography on soil erosion are estimated by the dimensionless LS factor as the product of the slope length (L) and slope steepness (S). Although the LS factor is usually either estimated or manually calculated from actual field measurements of slope length and steepness for local conservation planning purposes, labor-intensive field measurements are generally not feasible for modeling soil erosion at significantly larger spatial scales. Nowadays with newly developed procedures of geographic information system (GIS) technology, users can generate raster grids of the LS factor for various site characterizations and landscape ecology applications. The LS factor can be estimated from the DEM.

Generally as hill slope length or hill slope gradient increase, soil loss increases. As hill slope length increases, total soil loss and soil loss per unit area increase due to the progressive accumulation of runoff in the down slope direction. As the hill slope gradient increases, the velocity and erosivity of runoff increases.

4.4.2 Methodology and processing

Here, the digital topographic contours with 20 m interval initially obtained from Royal Thai Survey Department (RTSD) at scale 1 : 50,000 have been utilized. Digital topographic contours were then interpolated into raster DEM using topo to raster interpolator function of ArcGIS (Appendix F) after which slope in degree unit was calculated using ArcGIS. For preparing the LS-factor layer from digital elevation model, the revised equation was used for the study as follows:

(a) Slope length factor,

$$L = (\lambda/22.13)^{m}, \quad (4)$$

Where, m is a variable slope-length exponent related to the ratio β of rill erosion (caused by flow) to interrill erosion (principally caused by raindrop impact) by the following equation (Foster *et al*., 1977):

$$M = \beta/(l + \beta) \quad \text{and} \quad (5)$$

β can be computed from (McCool *et al*., 1989) as

$$\beta = (\mathrm{Sin}\theta/0.0896)/(3.0(\mathrm{Sin}\theta)^{0.8}+0.56) \quad (6)$$

(b) Steepness factor, S is computed from (McCool *et al.*, 1987)

$$S = (10.8\mathrm{Sin}\theta+0.03) \text{ for slope} < 9\% \quad (7)$$

$$S = (16.8\mathrm{Sin}\theta-0.5) \text{ for slope} \geq 9\% \quad (8)$$

Where,

λ = Slope length (cell size in meters),

θ = slope gradient map (degree)

ILWIS 3.4 software (Open source from http://www.ilwis.org) has been used for factor map calculations as it has many user friendly functions. The main advantage in using ILWIS software is attributed in having *Degrad* function, which returns a value in radians, often used in combination with trigonometric functions, and simplifies trigonometric raster map calculations. It also has an IFF functions for solving the slope steepness factor satisfying the slope percent critical limit of 9% condition, which is equivalent to 4.05 degree angle.

The final grid was evaluated to ensure that the data and parameters supplied to the software result a realistic value. The values of the slope length and the steepness factor (from 0.0301 to 12.02) generated as shown in the above Figure 4-6 lies with the limits of the values originally calculated and published in Wischmeier and Smith (1978) and Renard *et al*. (1997). The LS grid map thus had good confidence level for further carrying out the thesis work.

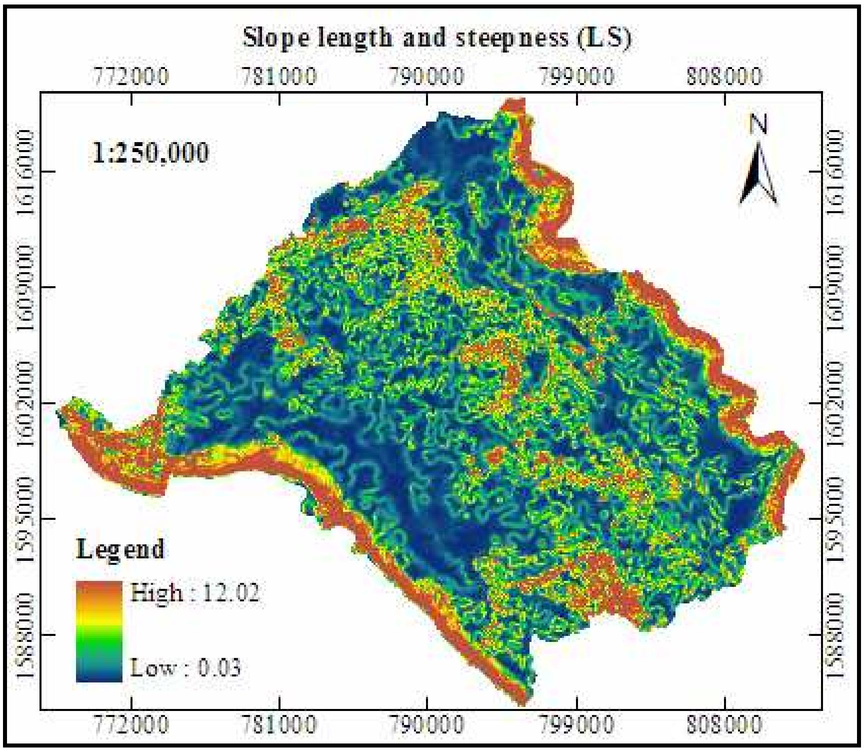

Figure 4-6 USLE LS-grid map

4.5 Vegetative cover and field support practice factor, C and P

4.5.1 Methodology and processing

The general procedure for generating C and P factor maps from land use and land cover map from Landsat imageries is depicted in Figure 4-7.

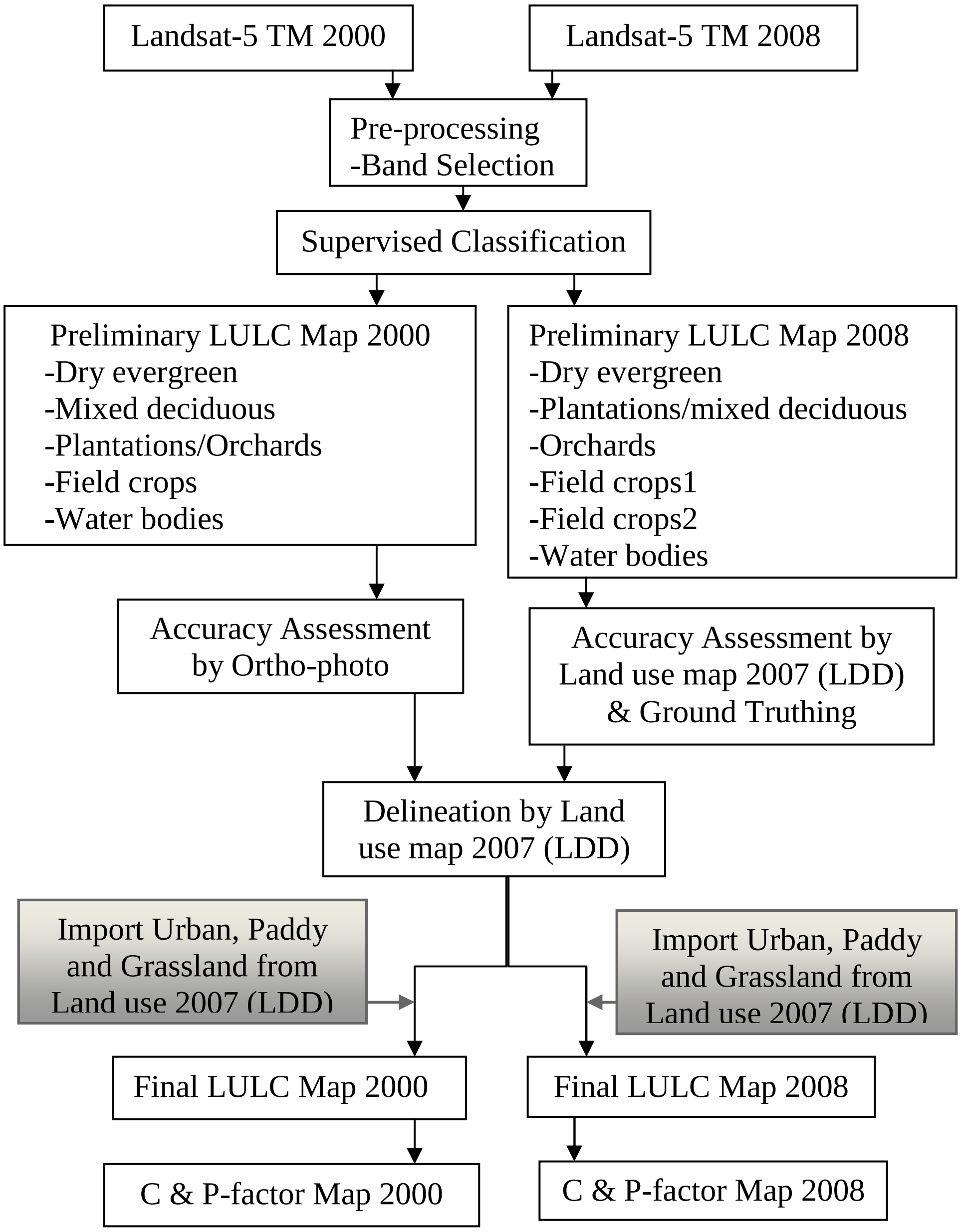

Figure 4-7 Procedures of obtaining C and P-factor maps

T Two dates of Landsat-5 TM in year 2000 and 2008 respectively have been used for land use and cover mapping**.** Since Landsat-5 TM image can be visually analyzed using only three bands at one time (assigned to red, green, and blue), the three-band combination that had the greatest amount of variance within the scene (Nield *et al*., 2007) by calculating the Optimum Index Factor (Jensen, 2005) can be used. The OIF technique simplifies that selection by quantitative evolution of the scene statistics and avoids the time-consuming of visual analysis process of large numbers of potential R-G-B combinations.

The algorithm used to compose OIF for any subset of three bands from the 20 three-band combinations that can be made from six bands of Landsat TM data (not including the thermal-infrared band) is given by:

$$OIF = \sum_{k=1}^{3} s_k \Big/ \sum_{j=1}^{3} Abs(r_j) \quad (9)$$

Where, s_k is the standard deviation for band k, and

r_j is the absolute value of the correlation coefficient between any two of the three bands being evaluated (Ongsomwang, 2007).

Both supervised and unsupervised classification complemented by various collateral sources like previous land use maps and aerial photographs have been carried. The numbers of reference points for accuracy assessments were calculated from:

$$N = \frac{B\Pi_i(1-\Pi_i)}{b_i^2}$$

(10)

Where, Π_i = ith class that has the proportion closest to 50%

b_i = desired precision for the class

B = upper (α/k) x 100 percentile of the chi square (χ^2) distribution with 1 degree of freedom

k = number of classes.

Stratified random design method was used for point's distribution in each class as each land use and land cover class gets equal chance of reference points for checking. The discrete multivariate techniques were more appropriate because remotely sensed data are discrete rather than continuous and are also binomially or multinomially distributed rather than normally distributed (Congalton and Green, 1999). The overall accuracy and kappa statistic were used to report the assessment. The overall accuracy incorporated only the major diagonal and excluded the omission and commission errors. Conversely, K computation incorporated the off-diagonal elements as a product of the row and column marginal. Therefore, depending on the amount of error included in the matrix, these may not agree (Ongsomwang, 2007). The assessment is carried using ortho-photographs for land use land cover map 2000 and used land use map 2007 of LDD and ground truthing in 2008 for land use map 2008. The *overall accuracy* of the classification map is determined by dividing the total correct pixels (sum of the major diagonal) by the total number of pixels in the error matrix (*N*), which is an estimate of Kappa is given by:

$$\hat{K} = \frac{N\sum_{i=1}^{k} x_{ij} - \sum_{i=1}^{k}(x_{i+} \times x_{+j})}{N^2 - \sum_{i=1}^{k}(x_{i+} \times x_{+j})}$$

Where,

k is the number of rows (land-cover classes) in the matrix;

x_{ij} is the number of the observation in row i and column j;

x_{i+} is the marginal totals for row i;

x_{+j} is the marginal totals for column j;

N is the total number of observations.

4.5.2. Vegetative cover C-factor map

The C factor is perhaps the most important USLE factor because it represents conditions that can be managed most easily to reduce erosion. The C factor is used with both the USLE and the Revised USLE (RUSLE) to reflect the effect of cropping and management practices on erosion rates, and is the factor used most often to compare the relative impacts of management options on conservation plans (Renard *et al*., 1997).

The C-factor values set by LDD (2000) for the various vegetation cover types have been assigned accordingly as shown in Table 4-6.

Table 4-6 Vegetative cover (C) and field support practice (P)

Land Cover Class	C Value	P Value	Remarks
Dry evergreen	0.019	0.1	* C value of 0.502 was used for land use map 2000 as the field crop was mainly corn. Since several field crops were grown and land use has changed in 2008, value of 0.60 was applied.
Mixed deciduous	0.048	1.0	
Plantations	0.088	1.0	
Orchards	0.15	1.0	
Paddy	0.28	0.1	
Grassland	0.015	1.0	
Field crops	0.502/0.6*	1.0	
Urban	0	0.0	
Water bodies	0	0.0	

Figure 4-8 and Figure 4-9 shows the C factor maps in two years respectively.

4.5.3 Field support practice P-factor map

The support practice factor, P is the soil-loss ratio with a specific support practice to the corresponding soil loss with up-and-down slope tillage (Renard *et al.*, 1997). The value of P for individual map unit is usually determined according to the conservation practices obtained from the field. In Thailand the value for P has not been established for all agricultural cover types except for paddy. For no practice, maximum values of 1 were assigned. The values P for nine different classes used are as given below as according to LDD (2000) is provided in Table 4-6. P factor raster grid maps were obtained as shown in Figure 4-10 and Figure 4-11 respectively.

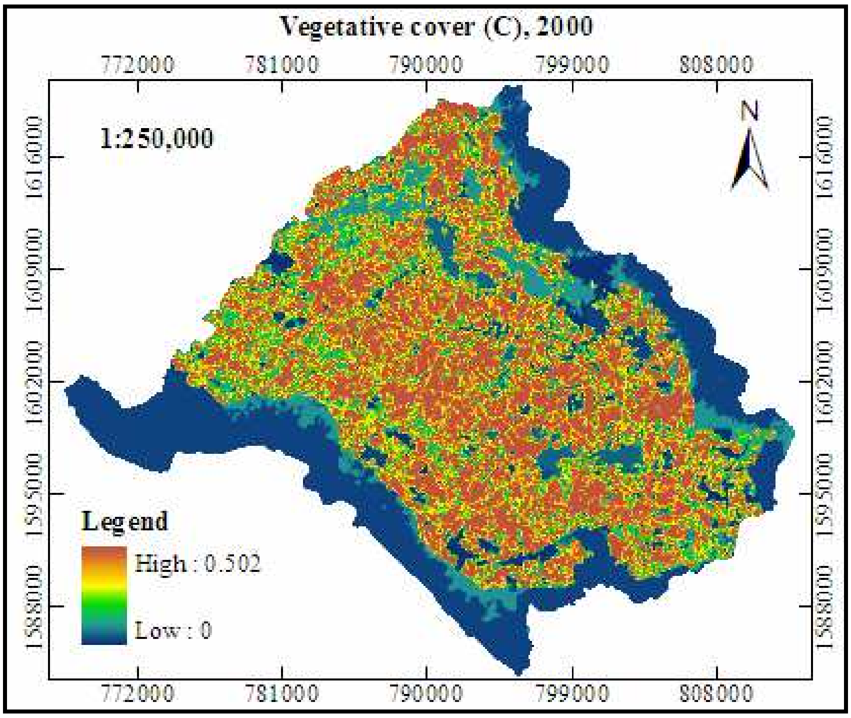

Figure 4-8 USLE C-grid map, 2000

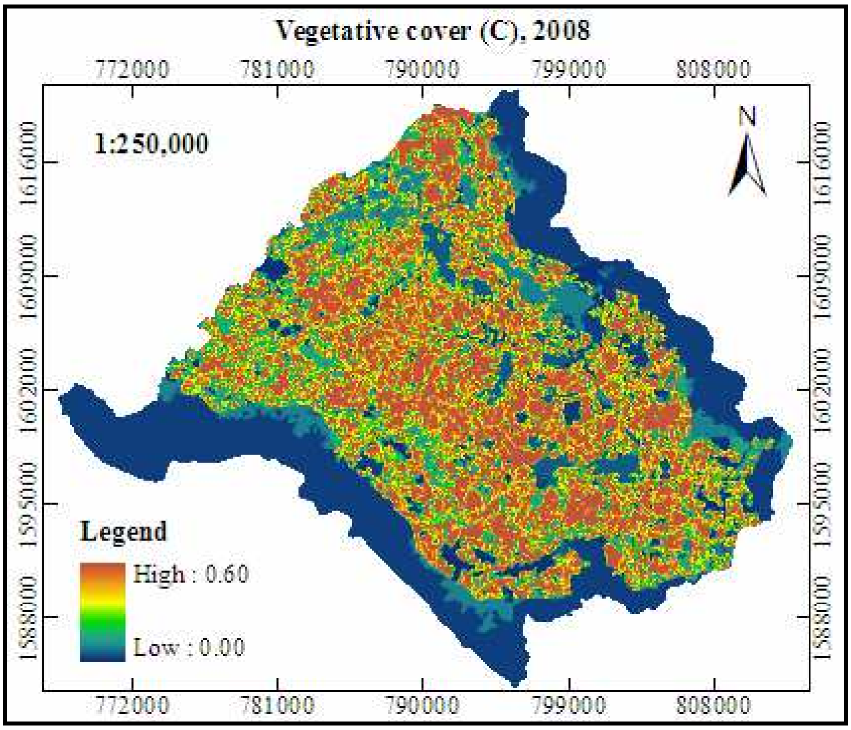

Figure 4-9 USLE C-grid map, 2008

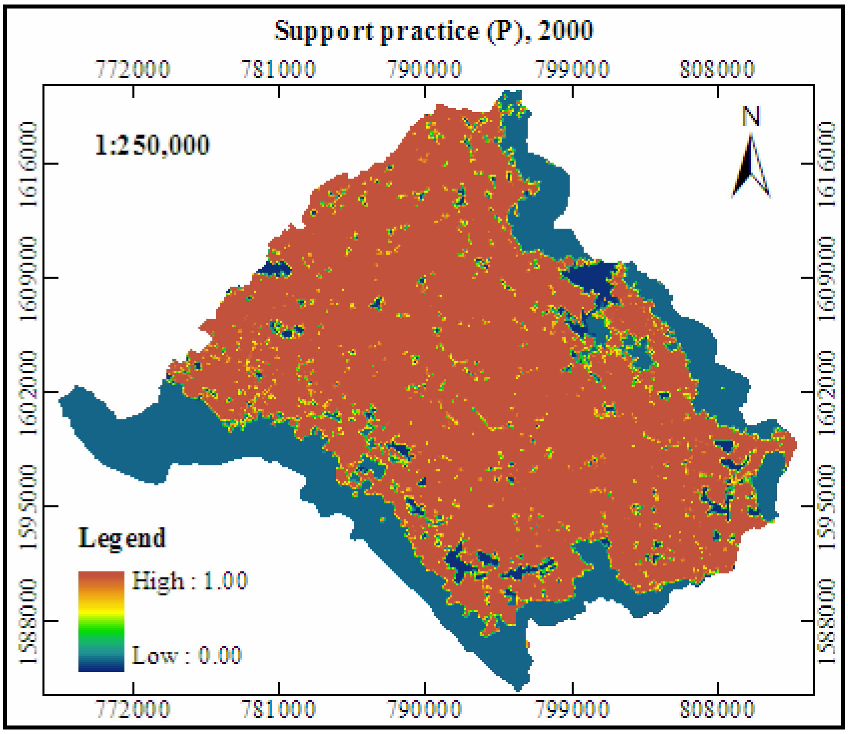

Figure 4-10 USLE P-grid map, 2000

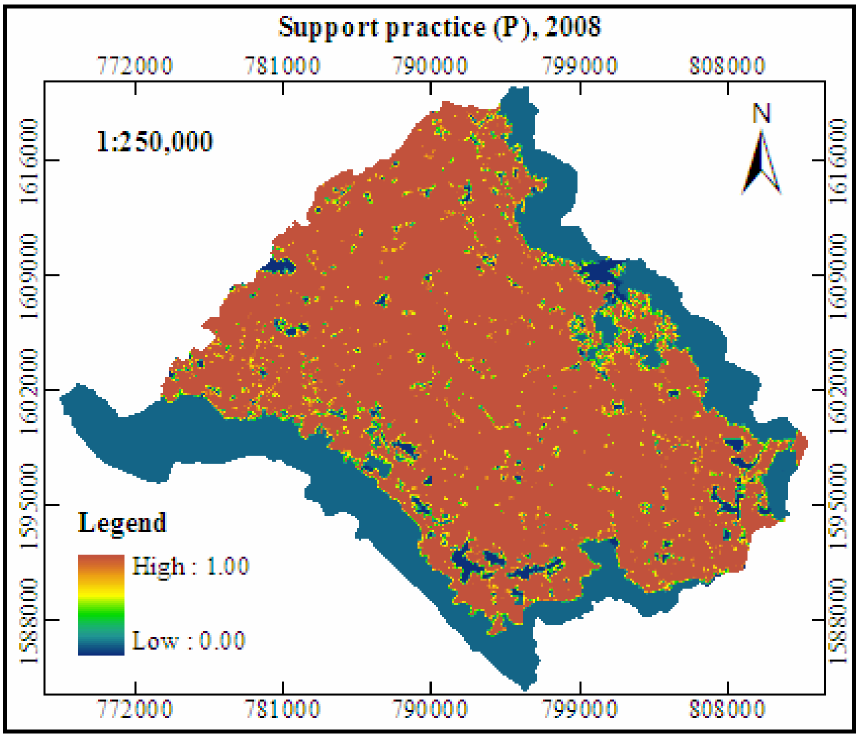

Figure 4-11 USLE P-grid map, 2008

4.6 Sediment yield

The bulk of the eroded material is deposited at intermediate locations, if the surface runoff cannot transport. However, some of the sediment eroded from the source can reach the nearest stream channel (Bhattarai and Dutta, 2006), which is expected to reach the basin outlet. However, sediment yield can be only estimated by SDR (sediment delivery ratio). It is computed as the ratio of sediment yield at the watershed outlet (point of interest) to gross erosion in the entire watershed.

Since eroded sediments are produced from different sources distributed throughout a basin, sediment delivery processes at basin scale have to be modeled by a spatially distributed approach (Ferro and Minacapill, 1995). It is to be noted that it can be affected by a number of factors including sediment source, texture, nearness to the main stream, channel density, basin area, slope, length, land use/land cover, and rainfall-runoff factors (Kinnell, 2004). One such SDR was proposed by Tim *et al*. (1992) quoted in (Fistikoglu and Harmancioglu, 2002) for the specific watershed area has been used. It is written as:

$$SDR = \exp^{(-k\,S\,L)} \tag{11}$$

Where, k = manning's roughness coefficient that varies with land cover;

S = slope in degree;

L = length of the flow path between each cell and the watershed outlet in metres. The manning's roughness coefficient values for the land use and land cover classes are tabulated in Table 4-7. Its value describes the relative resistance (or easiness) of soil transportation by runoff. For example, soil will be easily washed away by runoff more in agricultural field crops areas (0.035) than in dry evergreen forest (0.40). Low value indicates less resistant of soil to transportation by runoff and vice-versa.

Table 4-7 Manning's roughness coefficient for land covers (Prachansri, 2007)

Land use and land cover class	Manning's roughness coefficient
Corn/Field crops	0.045/0.035
Mixed deciduous	0.30
Dry evergreen	0.40
Grassland	0.24
Orchards	0.15
Paddy	0.10
Plantations	0.30
Urban	0.01
Water bodies	0.033

CHAPTER V

RESULTS AND DISCUSSIONS

5.1 Land use and land cover assessment in 2000 and 2008

5.1.1 Land use and land cover map 2000

Geo-corrected 7-band Landsat-5 TM (Appendix G) acquired on 5^{th} February, 2000 and originally obtained from GISTDA has been used. Six bands: 1, 2, 3, 4, 5 and 7 have been layer stack and made into a composite and was subset.

The band selection was achieved by OIF technique. Accordingly, band 1, 4 and 5 was found to have the highest OIF value, second followed by band 1, 5 and 7 and third by band 4, 5 and 7 as shown in Appendix H. Therefore, band 1, 4 and 5 was taken as the best choice for the study. While assigning band 5 to red, band 4 to green and band 1 to blue, it has been observed that it was very easy to recognize the details for classification.

Since supervised generally yielded a good result for less number of classes, emphasis has been given to it. Five major classes of land use and cover classes were initially classified. They are: dry evergreen, mixed deciduous, orchards/plantations, field crops and water bodies. Statistics, histograms, scatter-plots and contingency matrix were evaluated and found to be satisfactory for carrying out the work. Histograms were tried to be normally distributed. Even though as a matter of fact, it is difficult and challenging tasks especially while classifying remote sensing imageries for less number of classes as they generally contain more spectral values. To get an impression and satisfaction, the accuracy assessment was carried using ortho-photographs in the same year using 100 (Appendix I) sample reference points. The distribution is shown in Figure 5-1. The overall accuracy resulted 83.00% and kappa statistic value of 0.7875 (78.75%) as shown in Appendix J.

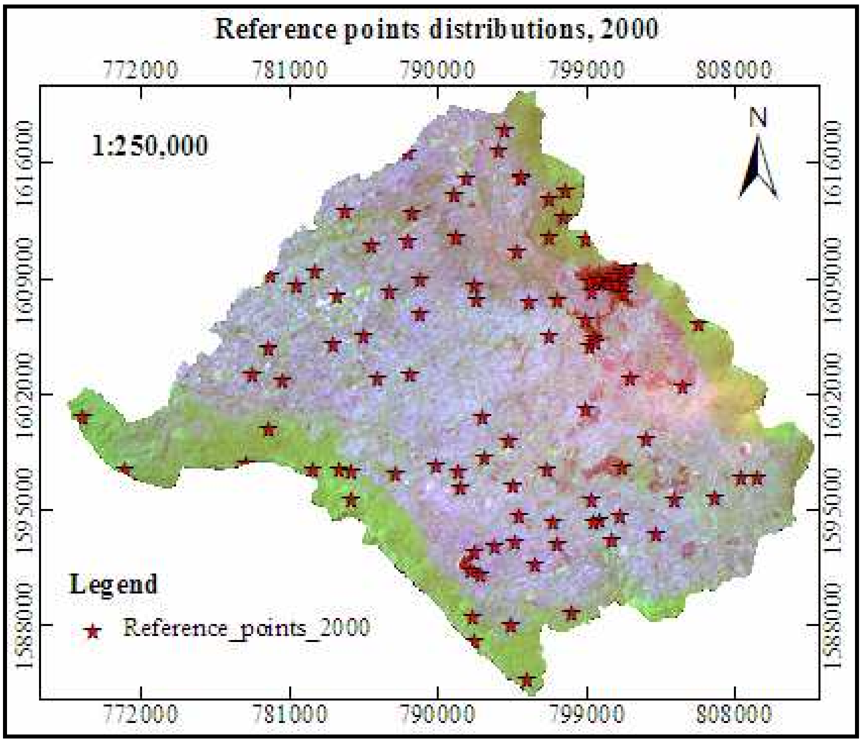

Figure 5-1 Reference points distribution for LULC, 2000

Once the evaluations were found to be satisfactory for further carrying out the work, the above mentioned land use and land cover were smoothened and then converted into vector format. Once in the vector version, the boundary delineation for all the land use and cover mapping have been used from the previous land use map of 2007 published at scale 1 : 25,000 by LDD. Visual interpretation, practical knowledge, experience and the theoretical background had been utilized during this phase of edition.

Orchards class was separated from the plantations class as they could not be classified separately as they have almost the same signatures in winter season but have different vegetative cover factor values. And also, since the area has major part of it as grassland, it has been added as new class from land use 2007 (LDD) and edited. Paddy and urban classes were imported from the land use map published in 2007. Final land use and land cover map 2000 was shown in Figure 5-2 and acreage of each land use and land cover in 2000 was summarized in Table 5-1.

Table 5-1 Acreage of land use and land cover classes in 2000

Land use and land cover	Sq. Km
1. Field crops	363.9
2. Mixed deciduous	30.1
3. Dry evergreen	172.1
4. Grassland	50.0
5. Orchards	64.5
6. Paddy	2.3
7. Plantations	64.3
8. Urban	26.5
9. Water bodies	12.2

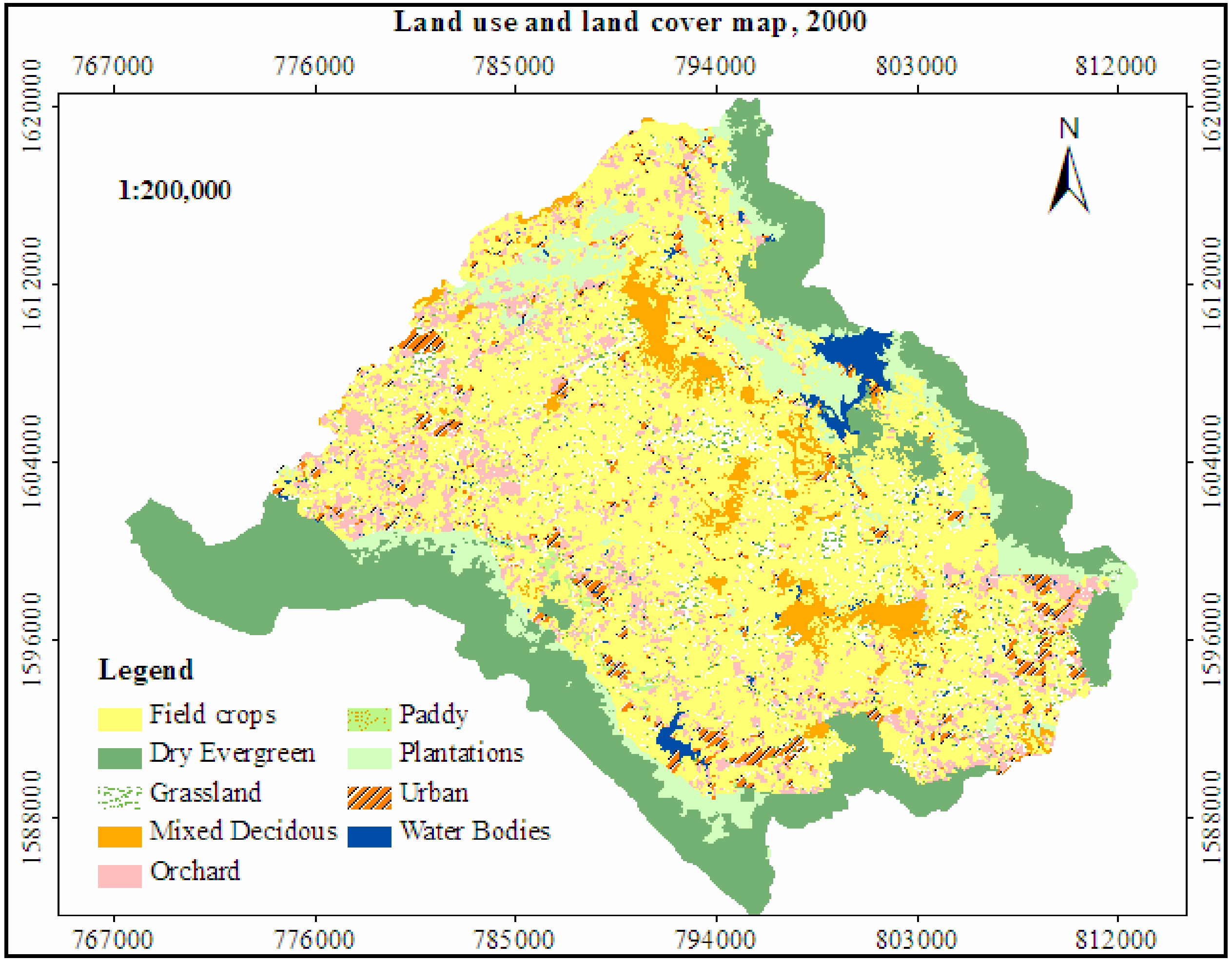

Figure 5-2 Land use and land cover map, 2000

5.1.2 Land use and land cover map 2008

Similar approach as that was applied for 2000 was also used while mapping the land use and cover map using Landsat-5 TM 2008 (acquired on 30th march, 2008). The best band combination by OIF was found to be band 1, 4 and 5 similar with that of Landsat-5 TM 2000 is shown in Appendix K. The six classes classified were dry evergreen, mixed deciduous/plantations, orchards, field crops1, field crops2 and water bodies. Mixed deciduous class was later separated from the plantations class as they could not be classified separately due to same signature but have different vegetative cover factor values. Accuracy assessment by ground truthing with an aid of land use map 2007 (LDD) has been carried out for 100 (Appendix L) sample reference points with similar methodology (Figure 5-3).

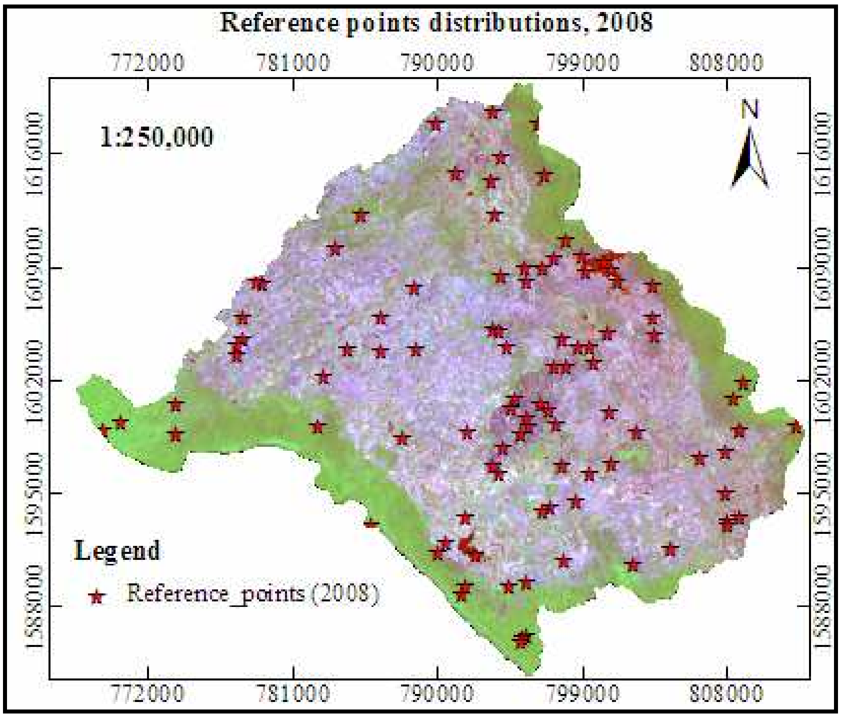

Figure 5-3 Reference points distribution for LULC, 2008

The overall accuracy was 89% with kappa value of 0.8677 (86.77%) as shown in Appendix M. The boundary delineation for each class was also used from the land use map 2007 published at 1 : 25000. The reason for using the same land use map of 2007 for delineating the boundaries of both the maps of 2000 and 2008 was attributed to the fact that the preparation of land use map 2007 have taken in fiscal year 2004-2005. Thus, it lies nearly between year 2000 and 2008, and the probability of change in both the year is assumed to be nearly same and minimal. Meaning that it is not so new for year 2008 and not so old for year 2000 and coming to the conclusion of good compromise. Final land use and land cover map 2008 was shown in Figure 5-4 and acreage of each land use and land cover in 2008 was summarized in Table 5-2. Another important thing is that the visit to field after mapping for verification and then incorporating corrections has proved the reliability of the map. Such editing has been incorporated after the field visit to avoid big blunders in the study.

Table 5-2 Acreage of land use and land cover classes in 2008

Land use and land cover	(Sq. Km)
1. Field crops	340.9
2. Mixed deciduous	30.0
3. Dry evergreen	170.6
4. Grassland	54.1
5. Orchards	81.0
6. Paddy	2.3
7. Plantations	69.2
8. Urban	26.5
9. Water bodies	11.2

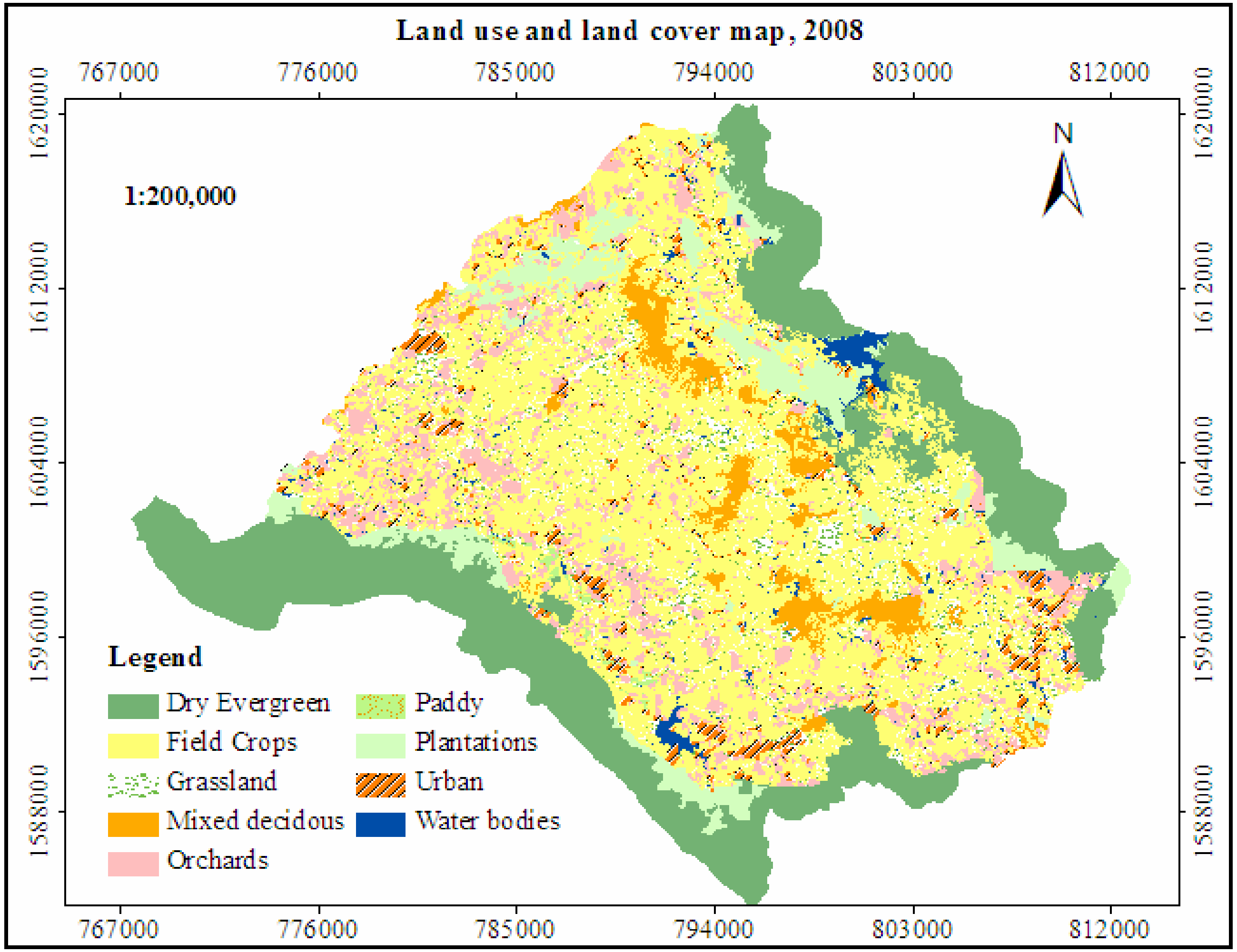

Figure 5-4 Land use and land cover map, 2008

In addition, some selected field pictures of major land use and land cover classes can be seen in shown in Appendix N

5.2 Land use and land cover change from 2000 to 2008

In the span of eight years, each class has undergone change from 2000 to 2008. Figure 5-5 shows the spatial locations of land use and land cover changes from 2000 to 2008 using post classification technique. The quantity of each change is as shown in Table 5-3.

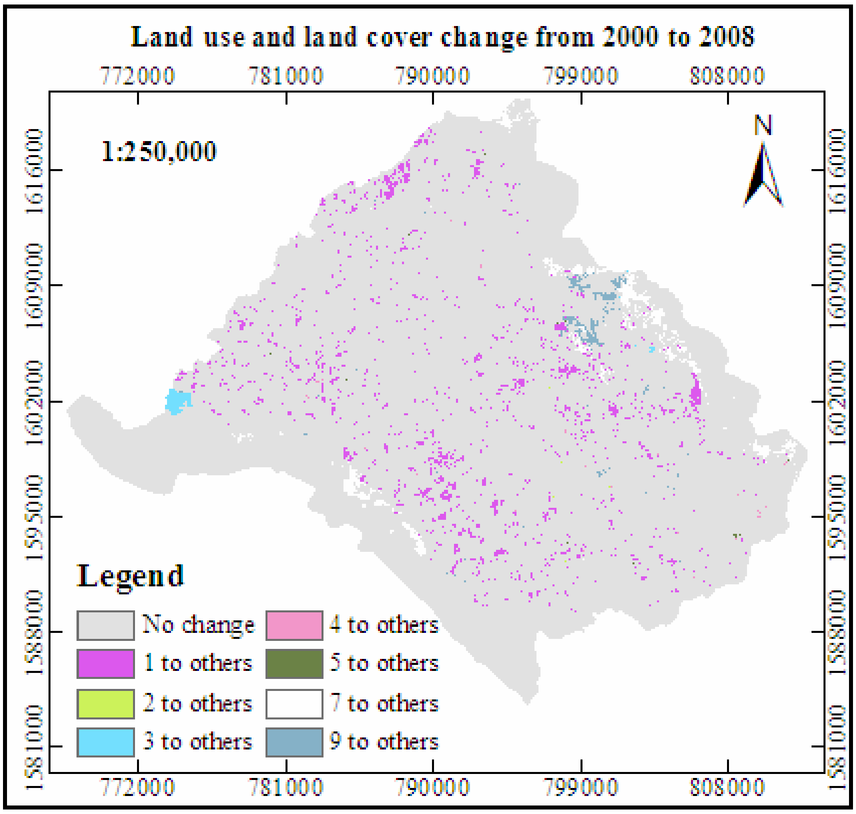

Figure 5-5 Land use and land cover change in two periods

The change indicated as “others” can mean change to any possible other eight land use and land cover classes. The numbers used in the legend to denote are as below:

1. Field crops
2. Mixed deciduous
3. Dry evergreen
4. Grassland
5. Orchards
6. Paddy
7. Plantations
8. Urban
9. Water bodies

Based on changes in Table 5-3, the status of change in 2008 for each class is discussed below:

- From field crops (1) to (grassland, orchards, plantations and water bodies): It shows that some awareness program on importance of land resource and the natural environment has been conveyed to the people from the concerned authorities. The result will surely have positive impact in controlling soil erosion problem in the study area. It indicated that the agricultural area has been decreased by (23 Sq. Km) in 2008 compared to 2000.

- Mixed deciduous (2) to water bodies: It can be seen that there is no change to other classes but only a small portions to water bodies.

- Dry evergreen (3) to (plantations and water bodies): It might be due to disturbance of dry evergreen forests that its area has been changed to plantations and water bodies by small portions and decreased by 1.5 Sq. Km.

- Grassland (4) to water bodies: Although this class was imported from land use map 2007 (LDD), however some editing using visual interpretations were carried since some changes was expected and it was found to have increased by 4.1 Sq. Km in 2008 from 2000.

- Orchards (5) to water bodies: The plantations and orchards classes could not be differentiated separately in 2000. However, the differentiation between these two was possible in 2008. This gave less change (0.20 sq. km) but while integrating changes with other classes; it has increased 16.5 Sq. Km in 2008.

- Plantations (6) to water bodies: Only a small portion was changed and generally found to have increased by 4.9 Sq. Km.

- Paddy (7) (No change): There is no change of area coverage for paddy class as they were exported from the LDD land use 2007 and left unedited as described earlier.

- Urban (8) (No change): There is no change of area coverage for urban class as they were exported from the LDD land use 2007 and left unedited as described earlier.

- Water bodies (9) to (dry evergreen, mixed deciduous, orchards, plantations and grassland): Although the water bodies were masked and assumed to have null erosion, still then conversion to other classes is a positive sign of reclaiming land, which has already been covered by water bodies. Another reason could be, in 2000 there was huge amount of rainfall as compared to 2007 and the area of water bodies have decreased by 1.00 Sq. Km in 2008.

Table 5-3 Land use and land cover change from 2000 to 2008

Area (Sq. Km)					**2008**					
2000	Field crops	Mixed deciduous	Dry evergreen	Grassland	Orchards	Paddy	Plantations	Urban	Water bodies	Grand Total
Field crops	339.8	0	0	4.4	16.7	0	1.2	0	1.8	363.9
Mixed deciduous	0	30.0	0	0	0	0	0	0	0.1	30.1
Dry evergreen	0	0	170.4	0	0	0	1.6	0	0.1	172.1
Grassland	0	0	0	49.6	0	0	0	0	0.4	50.0
Orchards	0	0	0	0	64.3	0	0	0	0.2	64.5
Paddy	0	0	0	0	0	2.3	0	0	0	2.3
Plantations	0	0	0	0	0	0	64.2	0	0.1	64.3
Urban	0	0	0	0	0	0	0	26.5	0	26.5
Water bodies	1.1	0.04	0.2	0.1	0.03	0	2.2	0	8.5	12.2
Grand Total	**340.9**	**30.04**	**170.6**	**54.1**	**81.0**	**2.3**	**69.2**	**26.5**	**11.2**	**785.7**

5.3 Soil loss results

The five grid (30 m) factor maps after verification have been overlaid using the raster GIS function and the final soil loss grid map thus obtained has been reclassified using manual method into 5 classes each defining the degree of severity by rating score with areas affected and percentages. The soil loss was rated and given the descriptions using the international standard as shown in Table 5-4.

Table 5-4 Soil loss in 2000 and 2008

Severity Class	Loss Rate (t/ha/y)	2000		2008		Descriptions
		Sq. Km	%	Sq. Km	%	
1	≤ 6.25	366.55	46.85	390.07	49.86	Very low
2	6.26-31.25	220.61	28.20	210.78	26.94	Low
3	31.26-125.00	150.59	19.25	139.54	17.84	Moderate
4	125.01-625.00	44.43	5.68	41.84	5.35	Severe
5	> 625.00	0.15	0.02	0.12	0.02	Very severe

The study obtained an average soil loss of 31.40 ton/ha/year in the year 2000 with minimum of 0.014 ton/ha/year and maximum of 923.26 ton/ha/year. The sum of all the actual soil loss was 25,378,115.86 tons in the watershed but it should be clearly understood that all these figures will not be able to reach down streams due to deposition on the way due to various barriers. The runoff may not be so strong to further transport the eroded soils. The soil loss severity in the year 2000 is shown in Figure 5-6.

The erosion rate of year 2000 was compared with that of study carried by Chandraprabha (2002) of Asian Institute of Technology, which has obtained an average erosion rate of 20.21 ton/ha/year in the same study area. The present study which obtained an average of 31.48 ton/ha/year, agreed with the earlier results in the same area. However, it has been noted that the methodologies used were bit different for erodibility factor K and the distributions and number of rainfall stations used were different too.

Similarly, the study obtained an average soil loss rate of 29.46 ton/ha/year in year 2008 with minimum of 0.014 ton/ha/year and maximum of 914.61 ton/ha/year. The sum of all the actual soil loss in the watershed was 23,722,216.29 tons. The result indicated that the amount of soil loss was more in year 2000 as the rainfall more. The soil loss amount in the year 2008 is shown in Figure 5-7. Soil loss in year 2008 could not be compared separately since there no data for comparison but it lies in reasonable limit with erosion rate of 29.46 ton/ha/year.

Furthermore, the field verification, which proved the reliability of results of applying the model, is shown in Figure 5-8. The location on the map for the "*very severe*" was identified and visited on the ground was found to be a severe rill erosion process, which has affected the land. It was found to be a gentle sloppy agricultural land, where the texture type is silty clay.

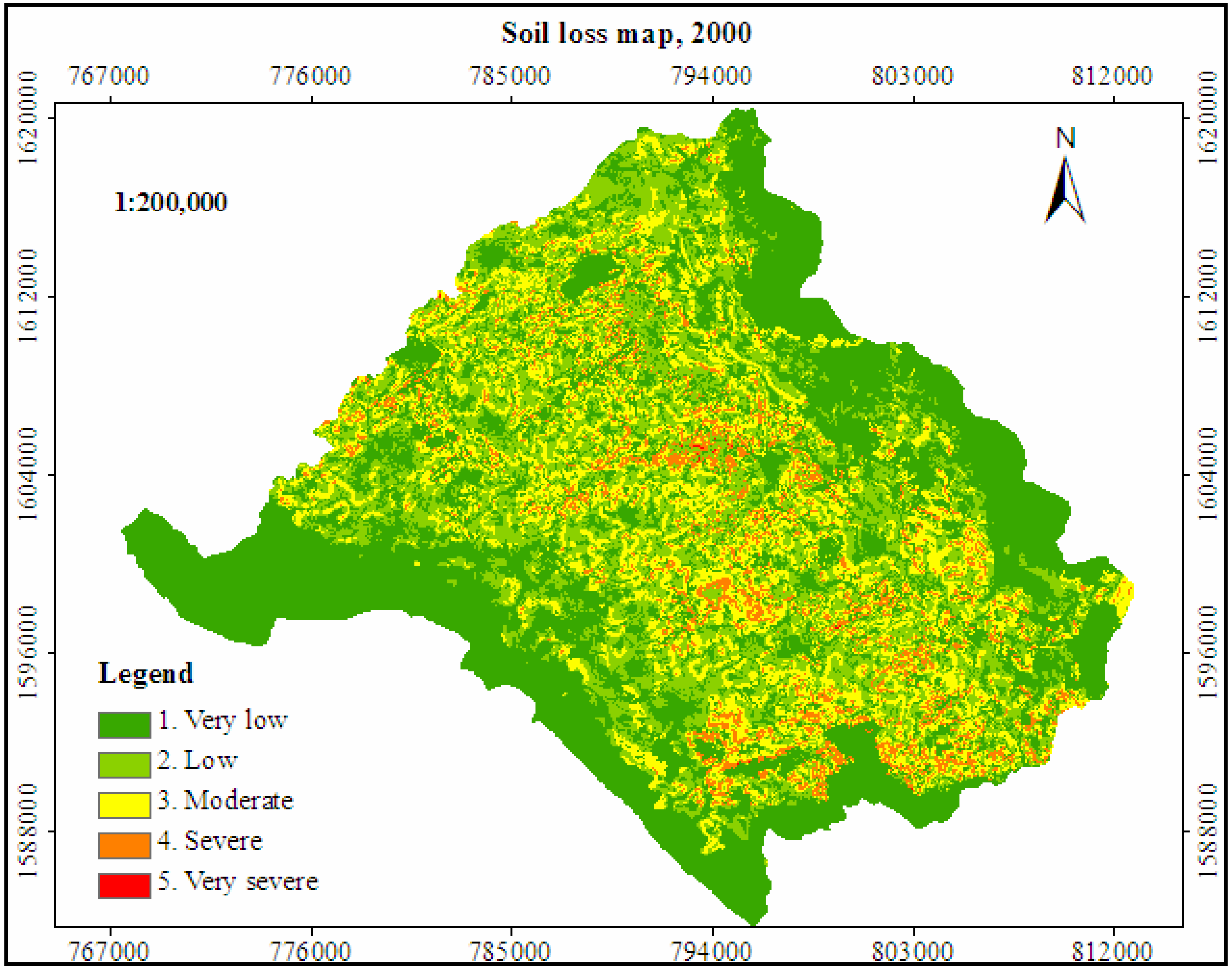

Figure 5-6 USLE soil loss-grid map for land use, 2000

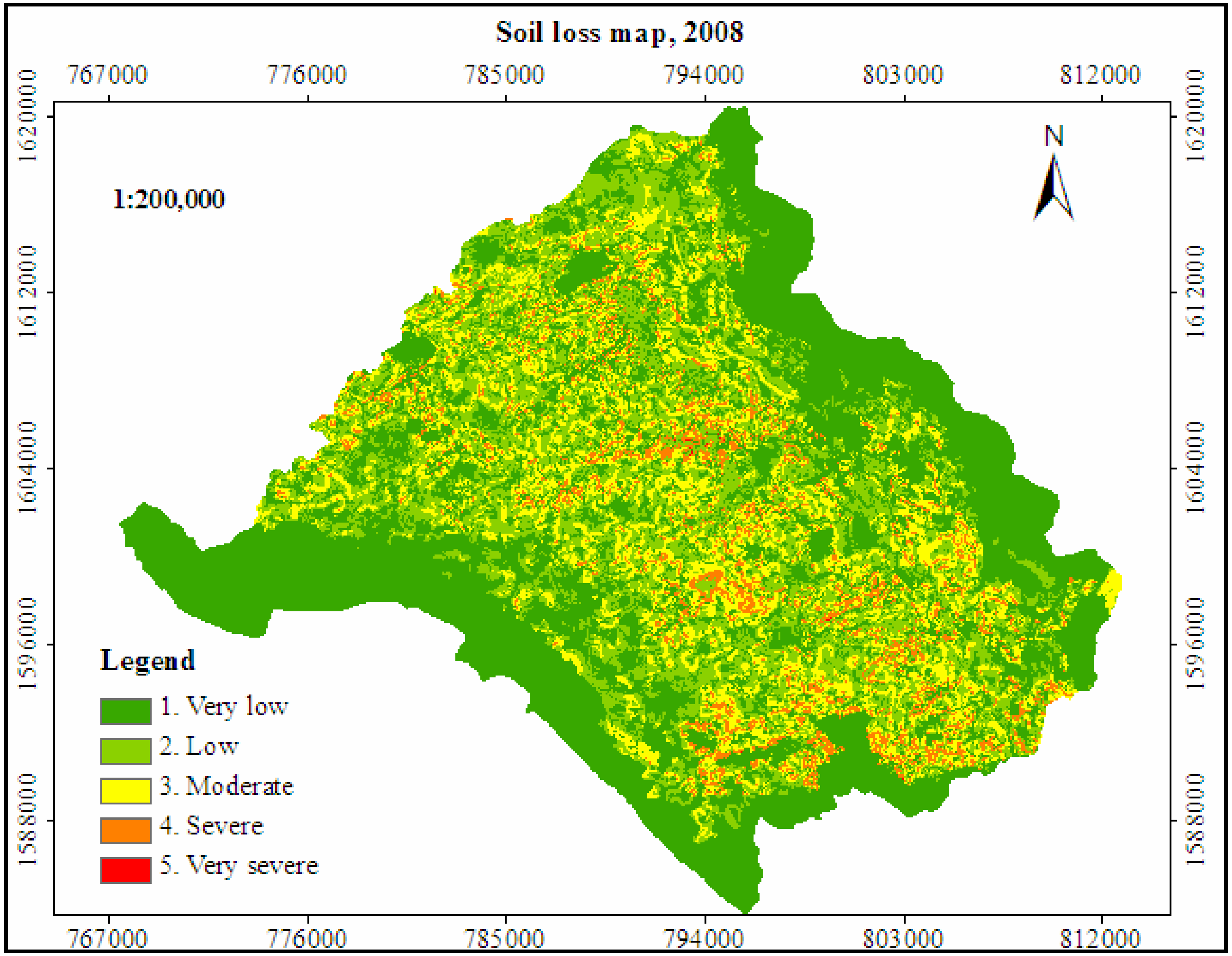

Figure 5-7 USLE soil loss-grid map for land use, 2008

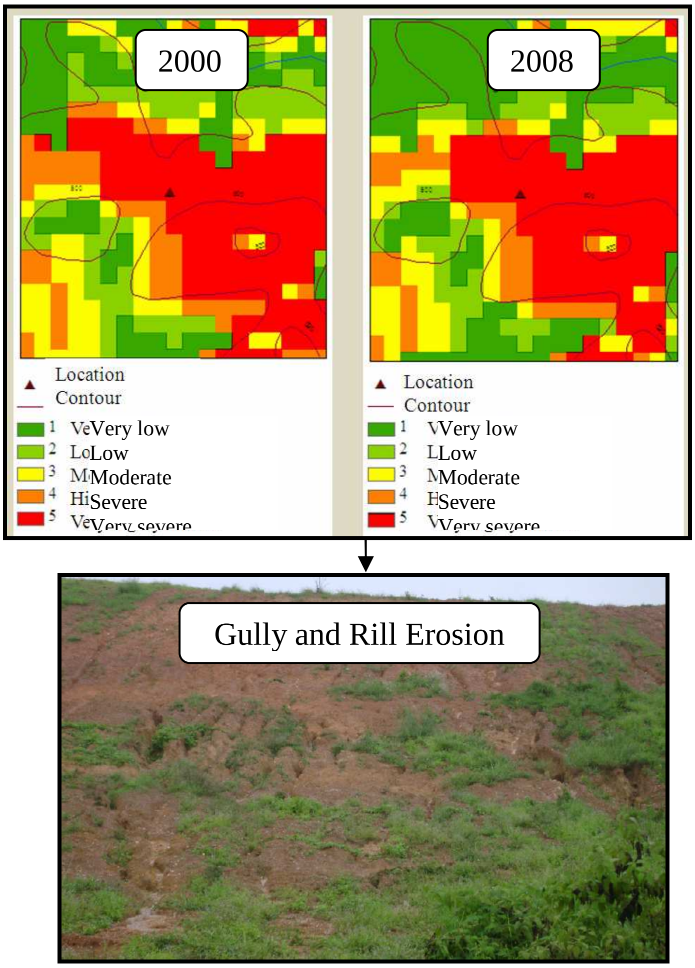

Figure 5-8 Location of “*very severe*” class verified

In addition, the status of soil loss severity change between 2000 and 2008 was calculated as shown in Table 5-5. From the table, it can be observed that the severity of soil loss has undergone changes from one severity class to another. It can be seen that these severity changes have both positive and negative impacts. Meaning is that when the severity has changed from low to higher degree of severity, there is negative impact of erosion either on agricultural land or environmental degradation. If the magnitude of severity has changed from severe to low, then it can have positive impact. The details of impacts of severity changed are depicted in Figure 5-9 and are described in the following sections.

Table 5-5 Soil loss severity changed in two years in areas

Area (Sq. Km) 2000	2008 Very Low	Low	Moderate	Severe	Very severe	Grand Total
Very Low	362.95	2.92	0.60	0.08	0.00	366.54
Low	21.71	195.79	3.10	0.00	0.00	220.59
Moderate	4.66	10.94	133.68	1.30	0.00	150.58
Severe	0.70	1.12	2.15	40.45	0.00	44.43
Very severe	0.02	0.00	0.00	0.01	0.12	0.15
Grand Total	**390.04**	**210.76**	**139.53**	**41.84**	**0.12**	**782.29**

The text (number) used for the legend in Figure 5-9 for both the year are as follows:

1. Very low (≤ 6.25 ton/ha/year)
2. Low (6.26-31.25 ton/ha/year)
3. Moderate (31.26-125.00 ton/ha/year)
4. Severe (125.01-625.00 ton/ha/year)
5. Very severe (> 625.00 ton/ha/year)

For example, legend “**15**” it can be interpreted as change from “From *Very low* in 2000 to *Very severe* in 2008”, which can have negative impact. Similarly others can be interpreted too.

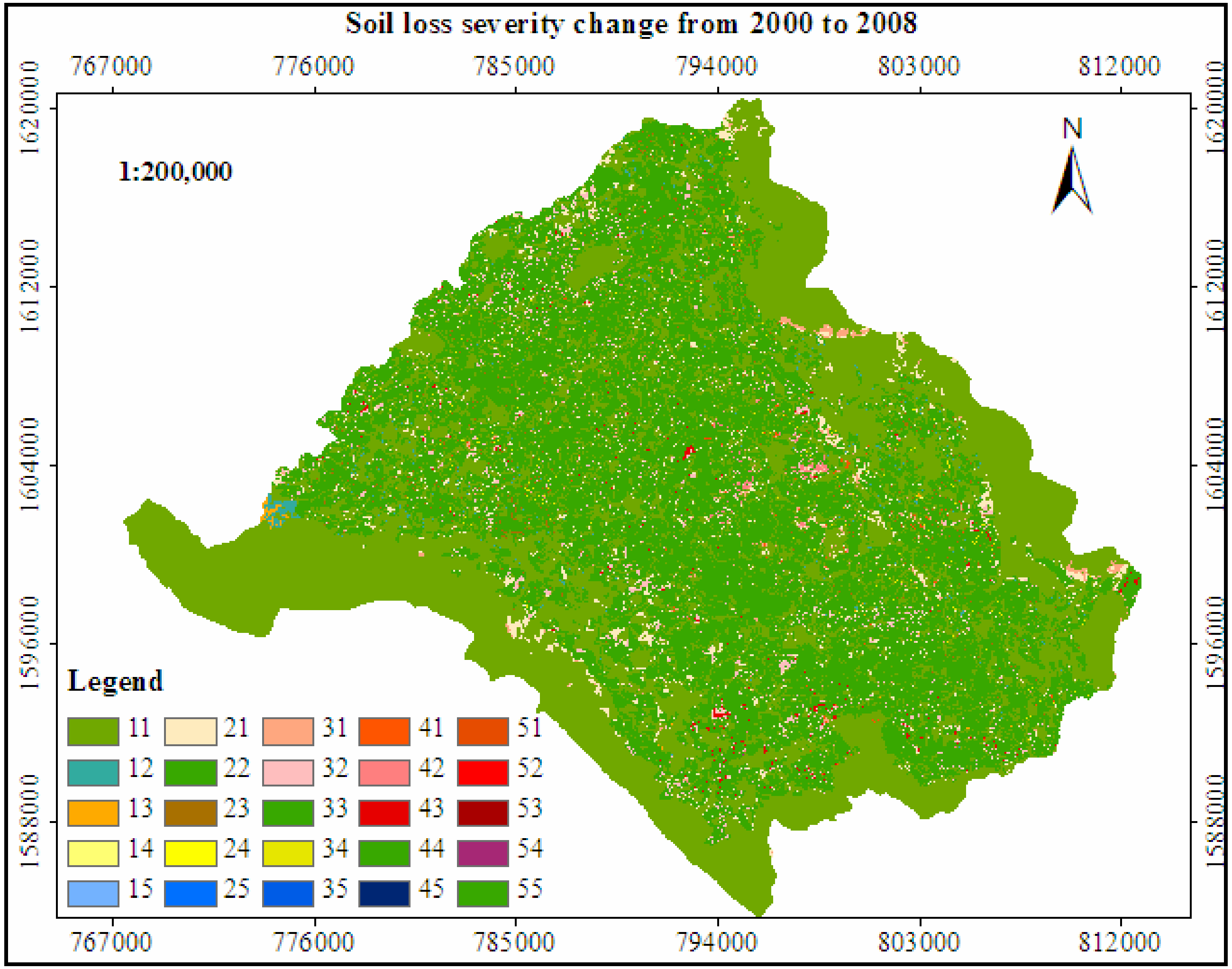

Figure 5-9 Soil loss severity change from 2000 to 2008

5.4 Identification of spatial soil loss distribution

Once the soil loss distribution maps have been obtained, it will have to be used by the land planners or developers and true understanding and interpretation of soil loss map is must for them. Therefore, some basic required interpretation of soil loss map is done here.

The soil loss severity will be in those spatial locations, where there is less or no canopy cover, with high rainfall and steep slopes or with clay loam soils. The very severe locations on the map indicate the areas with high soil loss rates leading to land degradation where water and soil conservation measures are required and to develop preliminary basin management strategies. These locations can also mean the areas adversely affected by erosion process or source for erosion. If it is in agricultural context, these areas are locations where the crop growth and yield will be less.

On the contrary, the very low eroded locations on the map indicate the areas with low soil loss rates. These spatial locations are the areas where the vegetation cover could be good enough for providing maximum protection from rainfall impact.

5.5 The effect of land use and land cover on soil loss

The only sustainable solution in preserving the finite land resource intact is by growing more and more plantations and orchards in the agricultural land and by keeping the forest undegraded. The importance of land use and land cover if other factors are held constant is described herewith: A land use and land cover map is the determining factor in modeling the soil erosion process. Vegetative cover plays a crucial role as erosion is significantly reduced under thick cover. As the protective canopy of the land cover increases, the erosion hazard decreases (Mkhonta, 2000). It protects the soil against the action of raindrops, increases the power of infiltration and also reduces the speed of surface runoff. As long as the land cover is unbroken, despite great erosive rainfall or steep slope, the runoff will still be maintained small. In the following sections, more evaluations on soil loss severity classes and the corresponding contributions from each land use and land cover classes is shown in Table 5-6 and Table 5-7 for two years respectively.

The contribution percentages of each land use and land cover classes was obtained after overlaying the land use maps on the soil loss maps for respective years. It clearly indicates the dependency of soil loss on land cover types and it can be found that soil loss has occurred mostly in agricultural lands (field crops) whereas the soil loss is relatively lower in dry evergreen, paddy and grasslands.

Table 5-6 Soil loss severity and amount of corresponding land use and land cover types in percentages and area (2000)

Area(Sq. Km)	Soil loss severity class 2000									
LULC 2000	**Very low**		**Low**		**Moderate**		**Severe**		**Very severe**	
	Sq. Km	**%**	**Sq. Km**	**%**	**Sq. Km**	**%**	**Sq. Km**	**%**	**Sq. Km**	**%**
Field crops	49.86	13.63	146.97	66.53	125.73	83.17	41.04	93.32	0.12	87.48
Mixed Deciduous	10.20	47.36	16.15	0.23	3.13	0.19	0.54	0.18	0.00	0.51
Dry Evergreen	173.23	10.06	0.52	3.87	0.28	2.19	0.08	2.82	0.00	9.72
Grassland	36.79	2.79	8.56	7.31	3.30	2.07	1.24	1.22	0.01	1.53
Orchard	26.22	7.17	27.81	12.59	9.70	6.42	0.64	1.45	0.00	0.07
Paddy	2.23	0.61	0.07	0.03	0.02	0.01	0.00	0.00	0.00	0.00
Plantations	30.47	8.33	19.79	8.96	8.35	5.52	0.26	0.60	0.00	0.00
Urban	25.20	6.89	0.70	0.32	0.46	0.30	0.14	0.32	0.00	0.69
Water Bodies	11.57	3.16	0.34	0.16	0.19	0.13	0.04	0.09	0.00	0.00
Grand Total	**365.76**	**100.00**	**220.91**	**100.00**	**151.17**	**100.00**	**43.98**	**100.00**	**0.13**	**100.00**

Table 5-7 Soil loss severity and amount of corresponding land use and land cover types in percentages and area (2008)

Area (Sq. Km)	**Soil loss severity class 2008**									
LULC 2008	**Very low**		**Low**		**Moderate**		**Severe**		**Very severe**	
	Sq. Km	**%**	**Sq. Km**	**%**	**Sq. Km**	**%**	**Sq. Km**	**%**	**Sq. Km**	**%**
Field Crops	46.75	12.00	134.01	63.53	118.08	84.42	38.74	93.43	0.09	82.74
Mixed deciduous	12.64	3.24	17.02	8.07	2.27	1.62	0.49	1.19	0.00	2.00
Dry Evergreen	184.78	47.43	0.56	0.26	0.33	0.24	0.09	0.21	0.00	0.41
Grassland	41.59	10.67	7.70	3.65	3.42	2.44	1.28	3.08	0.01	10.54
Orchards	37.49	9.62	33.45	15.86	9.40	6.72	0.52	1.27	0.00	0.00
Paddy	2.23	0.57	0.07	0.03	0.02	0.01	0.00	0.00	0.00	0.00
Plantations	28.52	7.32	16.98	8.05	5.66	4.05	0.15	0.36	0.00	0.00
Urban	25.27	6.48	0.66	0.31	0.43	0.31	0.13	0.32	0.00	0.23
Water	10.35	2.66	0.48	0.23	0.25	0.18	0.06	0.14	0.00	4.09
Grand Total	**389.62**	**100.00**	**210.92**	**100.00**	**139.86**	**100.00**	**41.47**	**100.00**	**0.11**	**100.00**

5.6 Sediment yield in 2000 and 2008

The SDR in the present study was based on land cover, slope and length of flow path (Appendix O) of the study area. It is site specific and assumed to be accurate. SDR calculation gave the true expected values ranging from 0 to 1. The two important SDR values were “0” and “1”. When SDR value equals “0”, it indicates that the eroded soil materials were not transported by runoff. In contrary, when SDR equals “1”, the whole amounts of eroded materials were assumed to be transported by runoff. Previous study showed that SDR value increased down slope along stream channels. Similarly, the present study obtained the same result as shown in Figure 5-10 and Figure 5-11 in 2000 and 2008. It can be observed that the level of yield was highest when the SDR value ranged from 0.85 to 1.00 and almost all the soil eroded are suppose to be transported to downstream but in reality it is not as they can get deposited on stream or river beds. The present study obtained more yield downstream as upslope eroded soil could not be reached downstream due to long flow path length of which they must have got deposited on the way. More explanation of the exponential function of SDR and descriptions are provided in Appendix P.

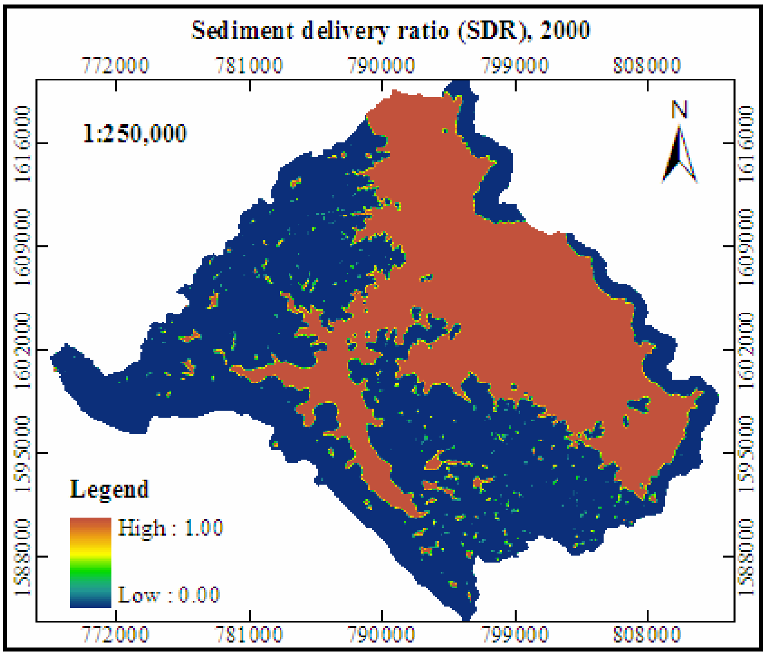

Figure 5-10 SDR map of study area, 2000

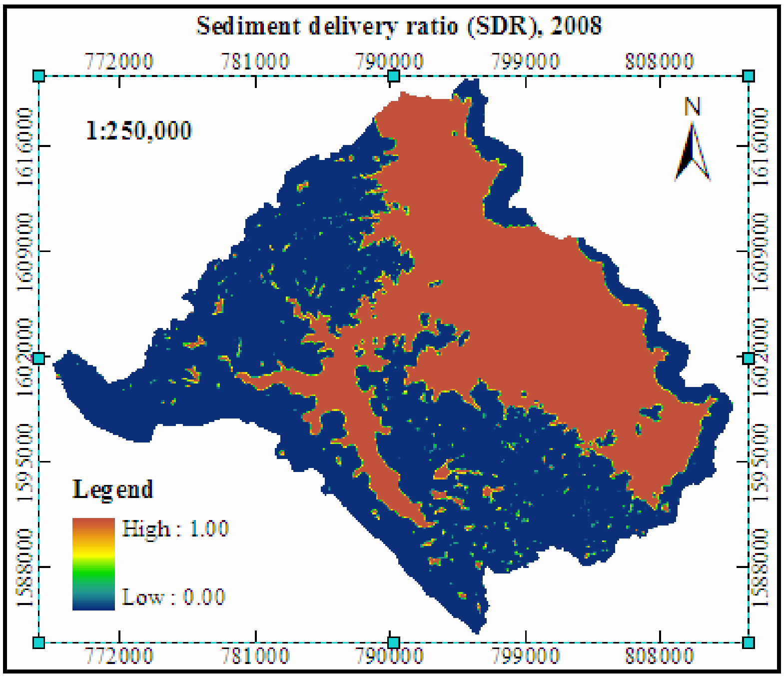

Figure 5-11 SDR map of study area, 2008

The sediment yield in two years is shown in Figure 5-12 and Figure 5-13 respectively. The average yield in 2000 was 12.84 ton/ha/year with minimum of 0.014

ton/ha/year and maximum of 923.26 ton/ha/year amounting to 10,374,472.94 tons in the watershed. In 2008, the average yield was 12.03 ton/ha/year with minimum of 0.014 ton/ha/year and maximum of 914.61 ton/ha/year amounting to 9,722,786.67 tons in the watershed. The figures showed the location of potential sources for contributing yield in two years, which was assumed to have reached in the reservoir however it is not.

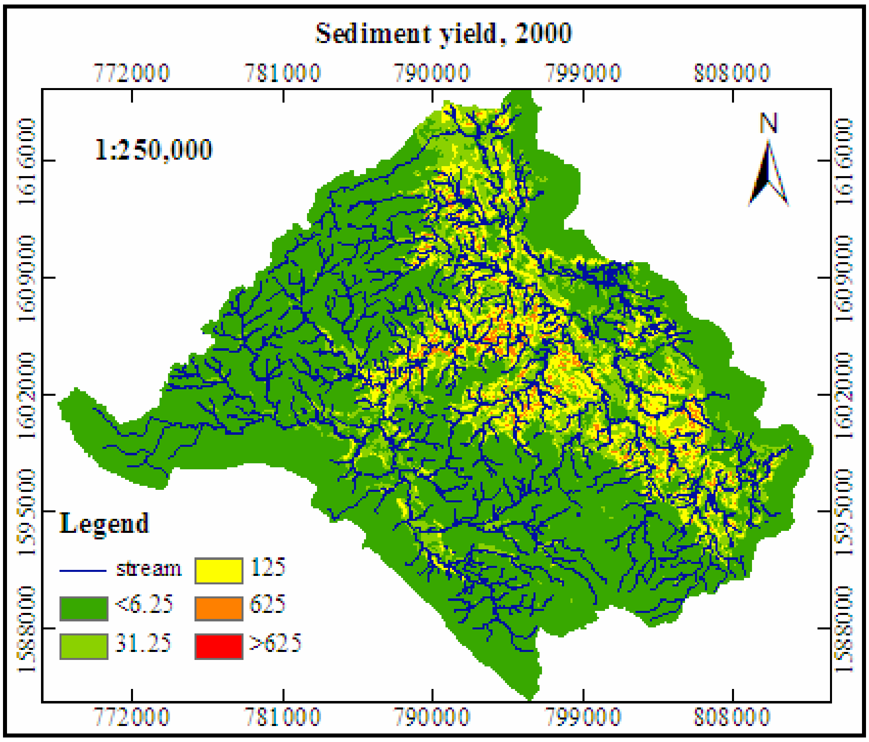

Figure 5-12 Sediment yield map, 2000

One such evidence from the field verification is shown in the Figure 5-14. It clearly indicated that the sediments which were assumed to have reached at the watershed outlet got deposited on stream banks.

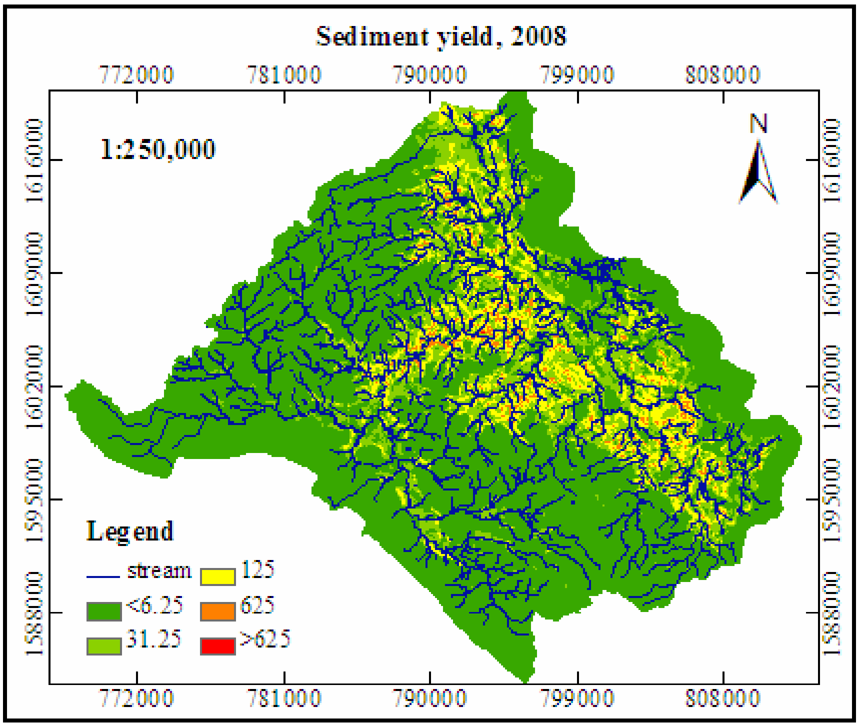

Figure 5-13 Sediment yield map, 2008

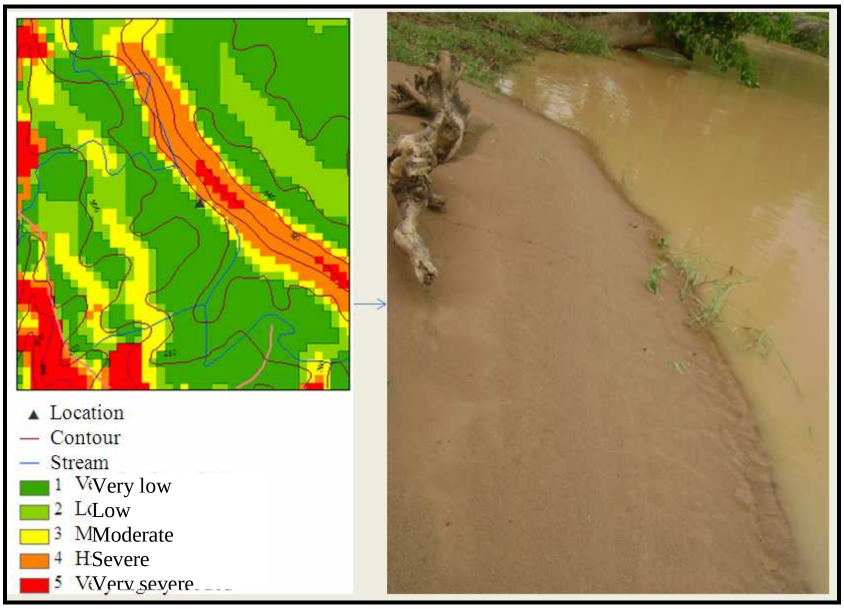

Figure 5-14 Deposits of sediments in the stream beds

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The integration of RS/GIS technology with USLE made possible to assess the land erosion process in the area. Having seen that erosion as one main type of agent has affected the land; it should not be seen as an end in itself. In this context, the need of reclaiming going-to-be and degraded land to its productivity capacity is must. All the land users and officials dealing these issues should be more practical in resolving this problem. Otherwise, if the current trend is allowed to continue, the consequences will go from very bad to worse in the near future. It is because, the agricultural systems is the only source of income for the people. They kept on growing various field crops for sustaining their daily lives, which has increased the amount of soil loss. In addition to this, the area is undulating with small hills, where the soils detached by rain drops impact can be reached to stream channels very easily.

It was observed that in many parts of the study area, the soils have become thin and stony. There are signs of rill and gullies due to erosion process. It was deeply felt that the concerned officials of royal government require great effort for improving the land resource in the area and to familiarize the farmers about the likeliness of hazard of excessive loss of soil. Control of erosion is required to protect agricultural land from damage and to prevent the sedimentation of dams and reservoirs.

The cloud free Landsat-5 TM imageries in 2000 and 2008 provided by GISTDA were main source of land use and land cover mapping for two years. Due to growth phrenology, it has been difficult to classify as land cover classes had same signature. However, Landsat imagery was found suitable for land use and cover mapping at watershed level due to its seamless and large area coverage when cloud-free. The soil, rainfall and geologic data as managed and documented by concerned agencies like LDD, RID and DMR were of good quality for carrying out this research task.

In the span of eight years, each class of land use and land cover has undergone changes to 2008 from 2000. These changes in land use land cover classes were observed to have great impact on soil loss amount. The soil loss change map indicated both increase and decrease rates. Moderate, severe and very severe classes were emphasized for the conservation purposes. When land use and land cover maps were overlaid on the erosion severity maps, it was found that agricultural field crops were more sensitive to erosion process than any other classes. It could also mean that agricultural field crops were mostly affected by erosion process. The lowest affected was found in dry evergreen, paddy fields and grassland.

The sediment yield based on the site specific SDR was generated. The SDR calculation was based on land cover, slope and flow path length from the point to the watershed outlet.

6.2 Recommendations and future improvements

Soil conservation is the only solution as soil once lost, it is not easily replaced. The meaning of conservation can be understood as not further wasting of resources, inputs and labours and also reducing the amount of soil erosion and maintaining soil fertility. It can be achieved by reducing the speed and amount of water running off, and keeping enough vegetation to protect the soil surface and to bind most valuable upper layer of soil together. Without soil conservation measures, this precious soil that took thousands of years to develop can blow or wash away in a matter of days or even minutes. Loss of topsoil will make fields more susceptible to drought, and cause farmers to rely more heavily on commercial fertilizers.

It is always wise on government's part to provide minimal help to farmers especially falling in severe erosion and critical zones and locations. Farmers cannot afford to have expensive control measures to protect the soil from erosion. However, it is still good to propose and instill a sense of conservation awareness to farmers.

Generally and many times the land resource has been found mostly degraded in agricultural land use system. By preventing land degradation through measures of conservation, farmers will be benefitted in terms of yield (Stocking and Murnaghan, 2000). It is therefore, the following section proposes and recommends

1) Some attainable and economically viable measures for protecting the limited natural soil resource and

2) Discusses the limitations of the present study and then recommend its need for future improvement.

6.2.1 Field conservation recommendations

Residue Management: Although, some management about the residue after the harvests haven practiced, some emphases and importance on it has to be explained to farmers. Leaving the residues on the field after harvests will revitalize the soil fertility and also help protect soil to wash away by erosion process.

Crop Rotation: The crop calendar depicts that land fallowing after harvest for several months, which is the main concern as it is making more susceptible to erosion. Therefore, crop rotation can be a good solution in minimizing the erosion risk. Other economical crops, which can be grown in the area needs to be studied well and grown during the off season of maize (corn).

Riparian (Strip) Buffers: Small portion of land is recommended to grow or to leave undisturbed especially as strips on the sloppy agricultural lands. This will prevent soil to be carried away easily by rain. It is also recommended to have such buffers between agricultural land and the river channels.

Minimized Tillage: More awareness by concerned authorities on negative impact of tillage along the slope is recommended. Although, practice of some tillage across slopes has been visible now in the field, however more has to be done from the government agricultural extension officers for implementations. Minimized tillage is also recommended as soil mixture will be less and tractors drown tillage is not recommended although it might not be feasible with conventional methods.

Planned Grazing Systems: It is highly recommended to have planned grazing systems and let the cattle graze on in the designated places and not to let them linger and grass as they like.

Terracing and Contouring: These are some of the main economical conservations practices generally followed. However building terraces may often be proved expensive for farmers, but if done, the soil loss will be minimal. Similarly, contouring if practiced will also reduce the soil loss from the plot.

Plantations and Orchards: more and more growth of forest plantations and orchards like mango, custard apple, teak, eucalyptus are recommended. The erosion problem will be less on these types of land use system.

Since construction of physical measures involves huge amount of money, it has been not brought to issue.

6.2.2 Limitations and recommendations of the study

It is well-understood that the models satisfying the users' requirements, which are reliable and having the characteristics of universal applicability with minimum amount of input factors, should be taken into use. The data requirements should not be too complex to understand, which will lead to faulty results. Since USLE satisfies most of the characteristics of being good model, it is highly recommended to use. Its reliability was also based on thousands of experimental researches world-wide.

The accuracy of soil loss estimation using USLE depends solely on input factors. Therefore, if regional factors of soil erosion are substituted by local factors, it will yield more precise results.

While processing for rainfall-runoff erosivity, it should be noted that it fulfills the purpose of the study whether it is site-specific or regional. In the developed countries like USA, the daily 30 minute rainfall intensity has been taken into consideration using automatic and sophisticated gauges. However, in the developing countries such data are not easily available. It is therefore as a last resort, regression equations, which were based on hourly or daily rainfall has to be used. These equations are normally developed by some responsible offices of the region. However, it should be cautioned that these equations are based on some span time of rainfall data, which are either seasonal or annual. Care should be taken as it has been found that nowadays, there are dozens of regression equations. Others may be global or regional regression equations. They should be used accordingly to serve the purpose of the study. If site specific or local regression equation is available and if can be developed, it is highly recommended as it can yield good result. The non-uniform distribution of rainfall stations created uneven interpolation and there is need for more rain stations to densify and to represent the good erosivity value.

Although, there are means and ways to obtain erodibility value, the most important thing to remember while assigning the erodibility is to understand the texture classes clearly (the percentages of clay, silt, fine sands) etc. Sometimes even in the main primary soil data, soil texture types are confusedly described. Of the 12 standard textural classes**,** sandy loams and loamy sands were often mixed and confused even by the high profile researches. The distinction between the two should be noted as they have very high difference in erodibility values. For example, the erodibility value for sandy loam and loamy sand in Northeastern Thailand is 0.26 and 0.05 respectively (LDD, 2000). If mistaken, there will be greater error in the soil loss result. The use of new unpublished geologic dataset had some limitations of having some unnamed names of the geological formations and the erodibility values were assigned based on major rock types present.

For slope length and steepness, hectic field measurements were carried before when there was no technology. Nowadays, there are various equations derived for it and with the availability of many techniques, DEMs and RS/GIS platforms, it is an easy task. However, it is highly recommended to use the most appropriate equation. While processing, efficient softwares have to be used. ILWIS 3.4 software (Open Source from http://www.ilwis.org) for slope length and steepness factor computations is highly recommended. It provides *degrad* functions, which returns a value in radians and often used in combination with trigonometric functions and simplifies trigonometric raster map calculations. It also has an IFF functions for solving the slope steepness factor satisfying the slope percent critical limit of 9% condition, which is equivalent to 4.05 degree angle.

The value for vegetative cover for each land use type has been set by Land Development Department (LDD, 2000). However, many studies have brought up wrong values. From the practical experience, it can be deducted that the canopy covers for plantations, orchards, deciduous forests in the year 2000 would be less whereas, canopy covers have grown big in year 2008. However, the limitation of using the same C- value irrespective of canopy covers for the same type of land use and cover type for two years, the erosion rate estimate will however remain same for each year. It is recommended that the value set by the LDD has to be used as the standard but more researches on it are also required. Also, many studies have wrongly assigned a value of “1” for both C and P for water bodies and urban settlements. It should be assigned “0” as vegetative cover and support practice terminology cannot be applied to these kinds of surfaces where erosion is actually assumed to be null.

More studies on site specific SDR is required as the present study could not went to its depth study.

GIS, is currently the only means by which soil loss estimation can be made at a catchment or watershed scale due to its ability to modify input parameters at ease. GIS therefore, allows soil loss estimation, previously limited to erosion plot studies, to be extended to a watershed scale and from data-rich to data-poor areas. The result is beneficial to decision-makers and conservationists in that a conservation strategy can be developed (Dennis, B. G., 2004). Therefore, its use for soil erosion assessment is recommended by all the GIS and other experts.

Similarly, RS is also the backbone while assessing erosion, without which there will be no land use and land cover maps. If higher resolution satellite imageries area available, it is always recommended. For mapping land use and land cover maps at watershed level for erosion assessment, Landsat imagery is sufficient.

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APPENDICES

APPENDIX A

INVERSE DISTANCE WEIGHTED METHOD OF INTERPOLATION

The main logic used in IDW interpolation is based on fundamental geographic principle. The things that are closer together tend to be more alike than things that are farther apart. For example, when trying to build the elevation surface, we can assume that the sample values closest to the prediction location will be similar. The sample number required will vary with the amount and distribution of the sample points and the character of the surface. If the elevation samples are relatively evenly distributed and the surface characteristics do not change significantly across the landscape, the predicted surface values from nearby points will be reasonable accurate.

To predict a value for any unmeasured location, IDW will use the measured values surrounding the prediction location. Those measured values closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away, hence the name inverse distance weighted. The general formula is:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i)$$

Where,

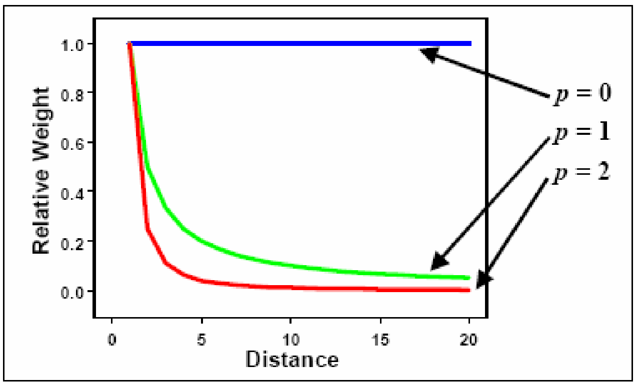
$\hat{Z}$ **(s$_0$)** is the value we are trying to predict for location $\mathbf{s_0}$; *N* is the number of measured sample points surrounding the prediction location that will be used in the prediction; λ_i are the weights assigned to each measured point that we are going to use. These weights will decrease with distance and $Z(\mathbf{s}_i)$ is the observed value at the location $\mathbf{s}_i$.

The formula to determine the weights is the following:

$$\lambda_i = d_{i0}^{-p} / \sum_{i=1}^{N} d_{i0}^{-p} \qquad \sum_{i=1}^{N} \lambda_i = 1,$$

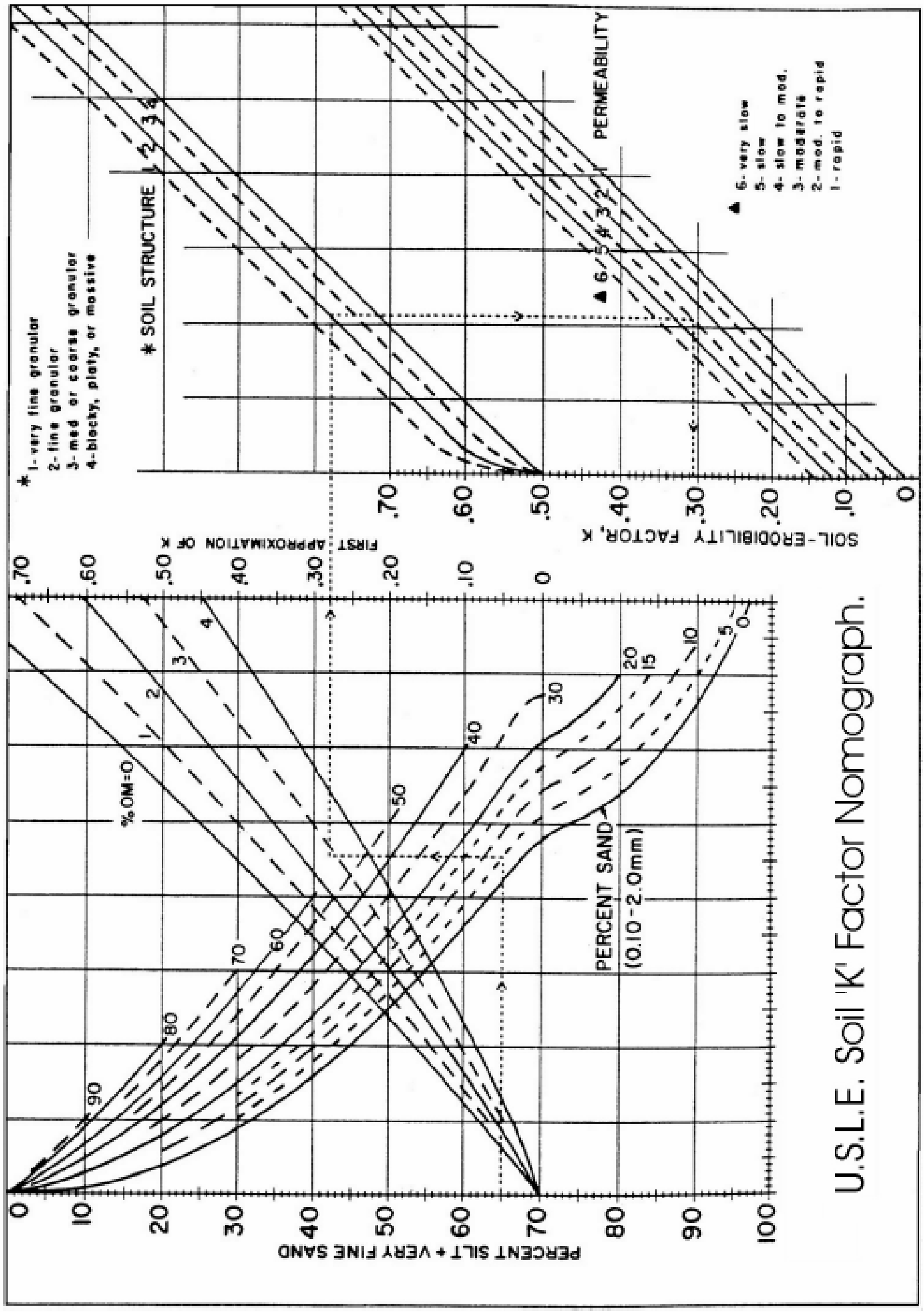
As the distance becomes larger, the weight is reduced by a factor of *p*. The quantity d_{i0} is the distance between the prediction location, $\mathbf{s_0}$, and each of the measured locations, $\mathbf{s}_i$.

The power parameter *p* influences the weighting of the measured location's value on the prediction location's value; that is, as the distance increases between the measured sample locations and the prediction location, the weight (or influence) that the measured point will have on the prediction will decrease exponentially. The weights for the measured locations that will be used in the prediction are scaled so that their sum is equal to 1.



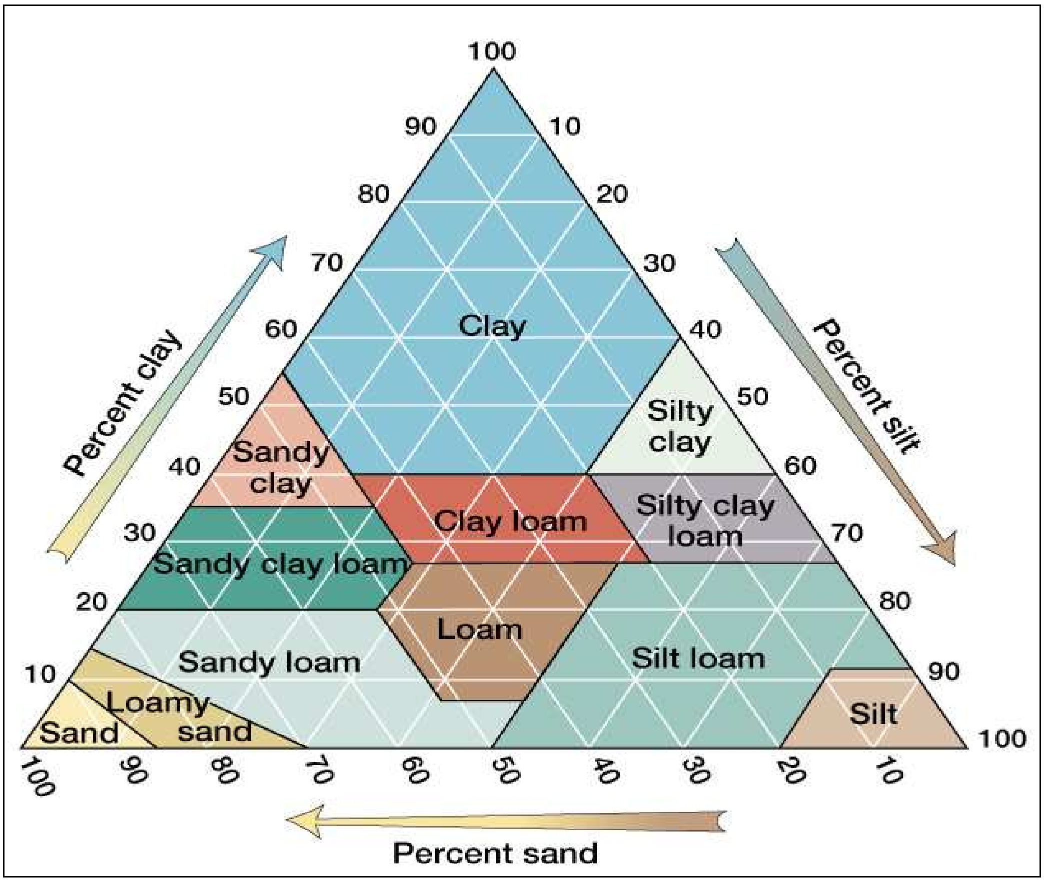
APPENDIX B

SOIL ERODIBILITY NOMOGRAPH



APPENDIX C

USDA SOIL TEXTURE TRIANGLE



APPENDIX D

SOIL TEXTURES

Soil texture is a soil property used to describe the relative proportion of different grain sizes of mineral particles in a soil. The smallest particles are *clay* particles as having diameters of less than 0.002 mm. The next smallest particles are *silt* particles and have diameters between 0.002 mm and 0.05 mm. The largest particles are *sand* particles and are larger than 0.05 mm in diameter. Furthermore, large sand particles can be described as *coarse*, intermediate as *medium*, and the smaller as *fine* (Brown, 2000).

Classifications are typically named for the primary constituent particle size or a combination of the most abundant particles sizes, e.g. “sandy clay” or “silty clay.” A fourth term, loam, is used to describe a roughly equal concentration of sand, silt, and clay, and lends to the naming of even more classifications, e.g. “clay loam” or “silt loam” (Brown, 2000).

A brief description of each texture type has been provided to understand the basics of classification and to differentiate each class more easily:

Clay: Clay is the finest textured of all the soil classes. Clay usually forms extremely hard clods or lumps when dry and is extremely sticky and plastic when wet.

Silt: Silt is similar to silt loam but contains even less sand and clay. Silt-sized particles are somewhat plastic, and casts can be formed that will bear careful handling.

Sands: Sands are loose and single-grained (that is, not aggregated together). Each individual sand grain is of sufficient size that it can easily be seen and felt.

Loam: Loam is soil material that is medium-textured. It feels as though it contains a relatively even mixture of sand, silt, and clay particles. Loam tends to be rather soft and friable.

Silty Clay: Silty clay is quite smooth, very sticky and very plastic when wet, and forms very hard aggregates when dry.

Sandy Clay: Sandy clay is somewhat similar to silty clay, but it contains much more sand and less silt.

Clay Loam: Clay loam consists of soil material having the most even distribution of sand, silt, and clay of any of the soil textural grades.

Silt Loam: Silt loam has rather small amounts of sand and clay and is composed mostly of silt-sized particles.

Sandy Loams: Sandy loams consist of soil materials containing somewhat less sand, and more silt plus clay, than loamy sands.

Loamy Sands: Loamy sands consist of soil materials containing 70-90% sand, 0-30% silt, and 0-15% clay. As such, they resemble sands in that they are loose and single-grained, and most individual grains can be seen and felt.

Silty Clay Loam: This soil material resembles clay loam in cohesive properties, but possesses more silt and less sand and thus has a rather smooth feel.

Sandy Clay Loam: Soil having this texture consists of materials whose behavior is dominated by sand and clay.

APPENDIX E

GEOLOGICAL ROCK TYPES

Geology is the study of earth structure and rocks and formation is a rock unit that is distinctive enough in appearance that geologists can differentiate it apart from the surrounding rock layers. Three general rock types are briefly discussed in the following sections in order to understand the glimpse of major geologic rock types used in this study.

Igneous rocks are produced by the crystallization and solidification of molten magma. Magma forms when rock is heated to high temperatures beneath the earth's surface. Most of the heat required to melt rock into magma comes from the Earth's central internal region known as the core. Some of these plumes melt through the Earth's solid lithosphere and can produce intrusive (below) igneous features and extrusive igneous features on the earth's surface. **Intrusive igneous rocks** such as diorite, gabbro, granite and pegmatite that solidify below Earth's surface; and E**xtrusive igneous rocks** such as andesite, basalt, obsidian, pumice, rhyolite and scoria that solidify on or above earth's surface.

Metamorphic Rocks are the alteration of existing rocks by either excessive heat or pressure, or through the chemical action of fluids causing chemical changes or structural modification to the minerals making up the rock. Rocks begin to change chemically at temperatures above 200° Celsius. At these temperatures, the minerals in the rock are broken down and transformed using different combinations of the available elements and compounds. As a result, new minerals are created. The metamorphic process stops when the temperatures become high enough (600 to 1200° Celsius) to cause complete melting of the rock. If rocks are heated to the point where they become magma, the magma when cooled creates new igneous rocks.

There are two basic types of metamorphic rocks:

a1) **foliated metamorphic rocks** such as gneiss, phyllite, schist and slate which have a layered or banded appearance that is produced by exposure to heat and directed pressure; and a2) **non-foliated metamorphic rocks** such as marble and quartzite which do not have a layered or banded appearance.

Sedimentary rocks are formed by the accumulation of sediments. There are three basic types of sedimentary rocks: b1) **Clastic sedimentary rocks** such as breccia, conglomerate, sandstone and shale, that are formed from mechanical weathering debris; b2) **Chemical sedimentary rocks** such as rock salt and some limestones, that form when dissolved materials precipitate from solution; and b3) O**rganic sedimentary rocks** such as coal and some limestones which form from the accumulation of plant or animal debris. Most sedimentary rocks are formed by the lithification of weathered rock debris that has been physically transported and deposited. During the transport process, the particles that make up these rocks often become rounded due to abrasion or can become highly sorted.

APPENDIX F

TOPO TO RASTER INTERPOLATION

Topo to Raster is a specialized tool for creating hydrologically correct raster surfaces from vector data of terrain components such as elevation points and contour lines. Contours were originally the most common method for storage and presentation of elevation information. The disadvantage lies in the under-sampling of information between contours, especially in areas of low relief. It is also the only ArcGIS interpolator specifically designed to work intelligently with contour inputs.

At the beginning of the interpolation process, Topo to Raster uses information inherent to the contours to build a generalized drainage model. After the general morphology of the surface has been determined, contour data is also used in the interpolation of elevation values at each cell. When the contour data is used to interpolate elevation information, all contour data is read and generalized. A maximum of 50 data points are read from these contours within each cell. At the final resolution, only one critical point is used for each cell.

APPENDIX G

LANDSAT SPACE MISSIONS

The National Aeronautics and Space Administration (NASA) embarked on an initiative to develop and launch the first Earth monitoring satellite to meet the needs of resource managers and Earth scientists. They are being used to support a wide range of applications in such areas as global change research, agriculture, forestry, geology, resources management, geography, mapping, water quality, and oceanography. The types of changes that can be identified include agricultural development, deforestation, natural disasters, urbanization, and the development and degradation of water resources. Background information and status of Landsat satellites is provided below in the table.

Satellite	**Launched**	**Decommissioned**	**Sensors**	**Agency**
Landsat 1	July 23, 1972	January 6, 1978	MSS/ RBV	1970s (NASA)
Landsat 2	Jan 22, 1975	February 25, 1982	MSS/ RBV	1983 (NOAA)
Landsat 3	Mar 5, 1978	March 31, 1983	MSS/ RBV	1985(Space Imaging)
Landsat 4	July16, 1982	June 15, 2001	TM/ MSS	(USGS)
Landsat 5	Mar 1, 1984	TM operational	TM/ MSS	(USGS)
Landsat 6	Oct 5, 1993	Didn’t achieve	eTM	
Landsat 7	Apr 19,1999	Operational	eTM+	

Landsats 5 carry both the MSS and the TM sensors; however, routine collection of MSS data was terminated in late 1992. The satellites orbit at an altitude of 705 km and provide a 16-day, 233-orbit cycle. These satellites also were designed and operated to collect data over a 185-km swath. The wavelength range for the TM sensor is from the visible, through the mid-IR, into the thermal-IR portion of the electromagnetic spectrum. Spectral range of bands, spatial resolution and applications of each band of Landsat-5 TM are:

Bands	**Wavelength (μm)**	**Cell size (m)**	**Applications**
Band 1	0.45 - 0.52	30	Penetrates water for bathymetric mapping along coastal areas and is useful for soil-vegetation differentiation and for distinguishing forest types.
Band 2	0.52 - 0.60	30	Detects green reflectance from healthy vegetation.
Band 3	0.63 - 0.69	30	Designed for detecting chlorophyll absorption in vegetation.
Band 4	0.76 - 0.90	30	Ideal for detecting near-IR reflectance peaks in healthy green vegetation and for detecting water-land interfaces.
Band 5	1.55 - 1.75	30	Crop drought detection; plant-vigor determination and in differentiating between clouds, ground ice, and snow. Because of the high absorption of water in this region, water-land delineation and the measurement of soil moisture content shortly after rain.
Band 6	10.40 - 12.50	120	Designed to assist in thermal mapping, and is used for soil moisture and vegetation studies.
Band 7	2.08 - 2.35	30	Useful for vegetation and soil moisture studies and for discriminating between rock and mineral types.

APPENDIX H

BAND SELECTION BY OIF FOR LANDSAT-5 TM 2000

Corr	B1	B2	B3	B4	B5	B7	Std. Deviation
B1	1	0.99403	0.96403	0.96930	0.94589	0.91041	35.38501
B2	0.99403	1	0.98433	0.96196	0.96695	0.94082	15.75374
B3	0.96403	0.98433	1	0.91747	0.98319	0.97736	18.20277
B4	0.96930	0.96196	0.91747	1	0.92010	0.86253	31.04440
B5	0.94589	0.96695	0.98319	0.92010	1	0.98656	47.13713
B7	0.91041	0.94082	0.97736	0.86253	0.98656	1	21.75666

Band Combination	SD	Corr	OIF	Rank
145	113.56650	2.83529	40.05465	1
157	104.27880	2.84286	36.68095	2
457	99.93819	2.76919	36.08932	3
345	96.38430	2.75736	34.95528	4
135	100.7249	2.89311	34.81544	5
125	98.27588	2.90687	33.80815	6
245	93.93527	2.84901	32.97120	7
147	88.18607	2.74224	32.15841	8
134	84.63218	2.85080	29.68717	9
357	87.09656	2.94711	29.55321	10
257	84.64753	2.89433	29.24598	11
124	82.18315	2.92529	28.09402	12
235	81.09364	2.93447	27.63485	13
137	75.34444	2.8518	26.41996	14
347	71.00383	2.75736	25.75066	15
127	72.89541	2.84526	25.61995	16
247	68.55480	2.76531	24.79100	17
123	69.34152	2.94239	23.56639	18
234	65.00091	2.86376	22.69775	19
237	55.71316	2.90251	19.19482	20

APPENDIX I

LIST OF REFERENCE POINTS, 2000

Ref_points ID	Easting	Northing	Class code	Ref code
1	794700	1596448	F2	F2
2	791850	1615048	F5	A2
3	801175	1594573	F5	F5
4	779800	1604748	F2	F2
5	789975	1597623	F2	F2
6	779900	1609248	A2	A2
7	792175	1588423	F1	F1
8	795975	1591698	F2	F2
9	799450	1595548	A2	F2
10	805900	1606273	F1	F1
11	792450	1607673	F2	F2
12	788225	1611298	A2	A2
13	795600	1607598	A2	A2
14	778850	1603173	F2	A2
15	788975	1608898	F2	F2
16	779800	1599923	F1	F1
17	799050	1611373	F1	F1
18	794550	1587948	F1	F1
19	804450	1595523	F2	F2
20	798200	1588648	F2	F1
21	795025	1594548	F2	F2
22	780675	1602798	F2	F2
23	785500	1605498	A2	A2
24	796900	1605473	A2	A2
25	787550	1597148	F2	F1
26	792325	1608598	F5	F5
27	808475	1596948	F2	A2
28	797700	1612773	F1	F1
29	783675	1604998	F2	F2
30	784775	1595548	F1	F1
31	794400	1599098	F2	F2
32	792750	1600598	F2	F2
33	809475	1596948	F2	F2

34	797400	1607723	F2	F2
35	800700	1593148	F2	F2
36	796700	1597448	F2	F2
37	797125	1594223	A2	A2
38	791025	1614148	F5	F5
39	792025	1591273	W	W
40	794150	1618098	F5	F5
41	799900	1594323	F5	A2
42	804925	1602473	F1	F2
43	799575	1594248	F5	F5
44	771025	1597448	F1	F1
45	788475	1612998	F5	F5
46	794925	1610723	F5	F2
47	793525	1592773	A2	A2
48	784075	1597373	F1	F1
49	794750	1593023	F5	F5
50	802800	1599223	A2	F2
51	784850	1597248	F1	F1
52	803325	1593498	A2	A2
53	791150	1611573	F5	F5
54	797825	1614298	F1	F1
55	781450	1608648	F5	F5
56	796875	1613898	F1	F1
57	792875	1598198	A2	A2
58	784500	1613173	A2	F2
59	797400	1592823	F5	F5
60	786000	1610998	A2	A2
61	783950	1607998	A2	A2
62	782550	1609423	F5	A2
63	788250	1616748	F5	A2
64	791475	1596348	A2	A2
65	778400	1597823	F1	F1
66	801225	1597473	F1	F2
67	782425	1597373	F1	F1
68	792325	1586948	F1	F1
69	768500	1600648	F1	F1
70	799000	1601073	A2	A2
71	795550	1584623	F1	F1
72	799350	1604848	A2	A2
73	787175	1608248	F5	F2
74	796825	1611573	F1	F1
75	786400	1602898	A2	A2
76	791300	1597348	A2	A2

77	801775	1602973	A2	A2
78	788975	1606898	F5	F5
79	788400	1603123	F5	F5
80	799425	1608198	F5	F2
81	793800	1616823	F5	A2
82	792275	1592323	W	W
83	800025	1608848	W	W
84	801350	1608073	W	W
85	801775	1609798	W	W
86	800425	1608698	W	W
87	801425	1608998	W	W
88	795125	1615048	W	W
89	799575	1605373	W	W
90	800925	1608748	W	W
91	801400	1609448	W	W
92	792625	1591073	W	W
93	795175	1615173	W	W
94	801700	1609748	W	W
95	806875	1595748	W	W
96	799300	1608823	W	W
97	799000	1606473	W	W
98	799850	1608948	W	W
99	800750	1609248	W	W
100	799650	1605198	W	W

APPENDIX J

ACCURACY OF LULC 2000 BY ORTHOPHOTOS

ERROR MATRIX

Reference Data

Classified Data	Water bodies	Dry evergreen	Field crops	Mixed deciduous	Orchards/ Plantations	Row Total
Water bodies	20	0	0	0	0	20
Dry evergreen	0	18	0	0	2	20
Field crops	0	0	17	0	3	20
Mixed deciduous	0	0	5	12	3	20
Orchards/Plantations	0	2	2	0	16	20
Column Total	20	20	24	12	24	100

ACCURACY TOTALS						**KAPPA (K^)**
Class name	Reference totals	Classified totals	Number correct	Producers accuracy	Users accuracy	
Water bodies	20	20	20	100.00%	100.00%	1
Dry evergreen	20	20	18	90.00%	90.00%	0.875
Field crops	24	20	17	70.83%	85.00%	0.8026
Mixed deciduous	12	20	12	100.00%	60.00%	0.5455
Orchards/ Plantations	24	20	16	66.67%	80.00%	0.7368
Totals	100	100	83			
Overall Classification Accuracy = 83.00%				Overall Kappa = 0.7875		

APPENDIX K

BAND SELECTION BY OIF FOR LANDSAT-5 TM 2008

Corr	B1	B2	B3	B4	B5	B7	Std Deviation
B1	1	0.99169	0.95108	0.96405	0.95735	0.91647	42.30054
B2	0.99169	1	0.97991	0.94448	0.97587	0.94914	21.12726
B3	0.95108	0.97991	1	0.87438	0.98158	0.98234	26.19915
B4	0.96405	0.94448	0.87438	1	0.90144	0.83149	40.50037
B5	0.95735	0.97587	0.98158	0.9014	1	0.98493	69.91199
B7	0.91647	0.94914	0.98234	0.83149	0.98493	1	33.43266

Band Combination	SD	Corr	OIF	Rank
145	152.7129	2.822855	54.09875	1
457	143.845	2.717867	52.92571	2
157	145.6452	2.858770	50.94681	3
345	136.6115	2.757401	49.54357	4
135	138.4117	2.884317	47.98769	5
245	131.5396	2.821801	46.61548	6
125	133.3398	2.906407	45.87788	7
357	129.5438	2.948862	43.93009	8
147	116.2336	2.712024	42.85860	9
257	124.4719	2.909953	42.77454	10
235	117.2384	2.937368	39.91274	11
134	109.0001	2.789517	39.07488	12
347	100.1322	2.688220	37.24850	13
124	103.9282	2.900229	35.83447	14
137	101.9323	2.849906	35.76692	15
127	96.86045	2.857309	33.89919	16
247	95.06029	2.725118	34.88300	17
234	87.82678	2.798775	31.38043	18
123	89.62695	2.922682	30.66600	19
237	80.75907	2.911401	27.73890	20

APPENDIX L

LIST OF REFERENCE POINTS, 2008

Ref_points ID	Easting	Northing	Class code	Ref code
1	793600	1612223	A4	A4
2	809075	1601773	F1	F1
3	796650	1593873	A2	A2
4	784450	1603873	A4	A4
5	791200	1614823	A2	A2
6	795425	1586023	F1	F1
7	808850	1598923	A2	A2
8	785925	1592898	F1	F1
9	782925	1602198	A4	A4
10	787950	1598373	A4	A4
11	799775	1602998	A4	A4
12	786550	1603873	A4	A4
13	799000	1609648	A4	F1
14	795450	1608998	F5	F5
15	797525	1599298	A4	A4
16	802550	1598773	A2	A2
17	795625	1586148	F1	F1
18	791850	1593523	A4	A4
19	795650	1608098	A2	A2
20	808050	1597473	A4	A4
21	797900	1590823	A2	A2
22	794475	1589148	A4	A4
23	799500	1604023	A4	A4
24	808825	1598823	A4	A4
25	793475	1614348	A2	A2
26	794375	1604023	A2	A2
27	786550	1605848	F5	A4
28	798650	1594473	A4	A4
29	791975	1598798	A4	A4
30	797850	1596623	A4	A4
31	788625	1607723	A2	A2
32	796775	1614673	F5	F5
33	793975	1608448	F5	F5

34	779175	1607998	A4	A4
35	773800	1598648	F1	F1
36	803450	1605873	A2	A2
37	791875	1589173	F5	F5
38	804550	1591473	A2	A2
39	793850	1596198	A2	A2
40	797775	1604548	A4	A4
41	777625	1603548	A2	A2
42	790625	1591898	A2	A2
43	802225	1590473	F5	A2
44	788700	1603973	A2	A2
45	789025	1603323	A2	A2
46	800800	1600023	A2	A2
47	791550	1588623	F1	F1
48	777600	1604223	A2	A2
49	797125	1594123	A2	A2
50	790100	1591248	F1	F5
51	803550	1607898	F1	F1
52	797375	1602823	F5	A2
53	798075	1610798	F1	F1
54	773725	1600398	F1	F1
55	782625	1599098	F1	F1
56	770300	1599423	F1	F1
57	808575	1600873	F1	F1
58	769275	1598898	F1	F1
59	796300	1617973	F1	F1
60	808175	1593173	F5	F5
61	800625	1604898	F5	F5
62	799575	1596148	W	W
63	793850	1605023	F1	F1
64	812375	1599173	F1	F5
65	795275	1585773	F1	F1
66	778000	1605923	F5	A4
67	798850	1604073	F5	F5
68	783725	1610198	F5	A2
69	793500	1605098	F5	F5
70	796625	1608923	F5	F5
71	794025	1615873	F5	A2
72	807975	1594948	F5	F5
73	795200	1598623	A2	A2
74	808850	1593523	W	A2
75	785275	1612273	F5	F5
76	789950	1617873	A2	A2

77	795750	1599098	A2	A2
78	794625	1600223	A2	A2
79	794125	1597773	A2	A2
80	801225	1608098	W	W
81	796950	1600073	A2	A2
82	777900	1604573	W	W
83	795225	1598623	A2	A2
84	798075	1602773	A2	A2
85	795625	1589423	W	W
86	803550	1604748	A2	F1
87	800925	1608823	W	W
88	800425	1609298	W	W
89	796425	1600548	A2	A2
90	778750	1608123	A2	A2
91	794900	1600798	A2	A2
92	799325	1608723	W	W
93	806400	1597148	W	W
94	792525	1591098	W	W
95	797300	1609548	W	W
96	793500	1618623	W	W
97	800950	1596798	W	W
98	808200	1593023	W	W
99	793550	1596698	A2	A2
100	795625	1599573	A2	A2

APPENDIX M

ACCURACY OF LULC 2008 BY LAND USE (LDD) AND GROUND TRUTHING

ERROR MATRIX

Reference Data

Classified Data	Dry evergreen	Field crops1	Field crops2	Mixed orchards	Water bodies	Mixed deciduous/ Plantations	Row Total
Dry evergreen	16	0	0	0	0	2	18
Field crops1	0	18	0	0	0	0	18
Field crops2	1	0	14	0	0	0	15
Mixed orchards	1	0	0	17	0	0	18
Water bodies	0	1	0	0	13	0	14
Mixed deciduous/ Plantations	0	2	2	2	0	11	17
Column Total	18	21	16	19	13	13	100

ACCURACY TOTALS						**(K^)**
Class name	Reference totals	Classified totals	Number correct	Producers accuracy	Users accuracy	
Dry evergreen	18	18	16	88.89%	88.89%	0.864
Field crops1	21	18	18	85.71%	100.00%	1
Field crops2	16	15	14	87.50%	93.33%	0.920
Mixed orchards	19	18	17	89.47%	94.44%	0.931
Water bodies	13	14	13	100.00%	92.86%	0.917
Mixed deciduous/ Plantations	13	17	11	84.62%	64.71%	0.594
Totals	100	100	89			
Overall Classification Accuracy = 89.00%						Overall Kappa = 0.8677

APPENDIX N

SOME FIELD PICTURES OF THE STUDY AREA


Evergreen forest


Permanent eucalyptus plantations


Mango orchard


Economic eucalyptus orchard


Corn


Visit to M33


No construction awareness


Velocity & suspended sediment measurement at M145


Road block


Flood at M145

APPENDIX O

MEASURING SLOPE AND FLOW IN GIS

Slope is used to describe the steepness, incline, gradient, or grade of a straight line. A higher slope value indicates a steeper incline. The slope is defined as the ratio of the “rise” divided by the “run” between two points on a line. The Slope function in GIS softwares calculates the maximum rate of change between each cell and its eight neighbors. Every cell in the output raster has a slope value. The lower the slope value, the flatter the terrain and higher the slope value, the steeper is the terrain. The output slope raster can be calculated as percent of slope or degree of slope. The gradient of slopes is calculated from a 3 x 3 cell window and Horn’s method assigns a weight of 2 to four immediate neighbours and 1 to corner cells. This 3 x 3 window is successively moved over the map to give the derivative slope. In the figure below, the neighbours are identified as letters from '*a*' to '*i*', with '*e*' representing the cell for which the slope is being calculated.

a	b	c
d	e	f
g	h	i

The rate of change in the x direction for cell '*e*' is calculated with the algorithm:

$\Delta x = [dz/dx] = ((c + 2f + i) - (a + 2d + g)) / (8 * cell\_size)$

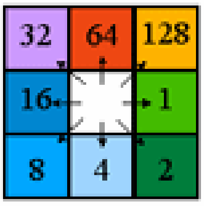
The rate of change in the y direction for cell '*e*' is calculated with the following algorithm:

$\Delta y = [dz/dy] = ((g + 2h + i) - (a + 2b + c)) / (8 * cell\_size)$

The basic algorithm used to calculate the slope is:

slope (degrees) = ATAN $(\sqrt{([\Delta x]^2 + [\Delta y]^2)}) * 57.29578$

The sink of the DEM will have to be filled to make the water flow. Water cannot flow across grid cells that contain a sink (depression). A sink is usually an incorrect value lower than the values of its surroundings. The creation of flow-direction GRID establishes the flow direction of steepest descent from each cell, which is calculated as: Change in z-value / distance * 100. If all neighbours are higher than the processing cell, it will be considered noise, filled to the lowest value of its neighbours and have flow direction towards this cell.



Direction Coding

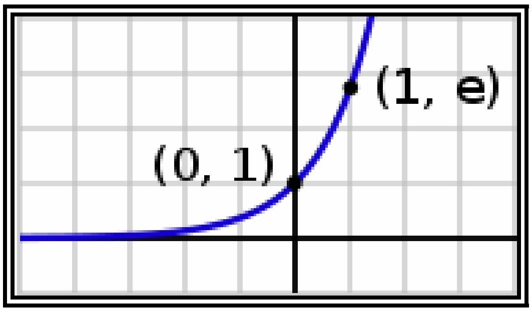
0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	2

A flow accumulation function creates a new GRID that shows number of cumulative increase in upstream cells that contribute water to the main basin. In the figure above, flow direction and accumulation is shown indicating number of cell flowing to the processing cell.

APPENDIX P

EXPLANATION OF EXPONENT FUNCTION IN SDR EQUATIONS

The **exponential function** is a function in mathematics. The application of this function to a value ***x*** is written as **exp(*x*)**. Equivalently, this can be written in the form e^x, where ***e*** is a mathematical constant, the base of the natural logarithm, which equals approximately 2.718281828, and is also known as Euler's number. The exponential function is nearly flat (climbing slowly) for negative values of *x*, climbs quickly for positive values of *x*, and equals 1 when *x* is equal to 0. Its *y* value always equals the slope at that point. As a function of the *real* variable *x*, the graph of $y = e^x$ is always positive (above the *x* axis) and increasing (viewed left-to-right). It never touches the *x* axis, although it gets arbitrarily close to it.



Exponential function for negative x is defined by EXP (-x) = e^{-x}, where e is the constant 2.718.

For example:

- To find the value of $e^{-0.94}$
- Have to find the row with x = 0.9
- Then find the column 4, the number inside the cell is 0.39.

x	**0.00**	**1.00**	**2.00**	**3.00**	**4.00**	**5.00**	**6.00**	**7.00**	**8.00**	**9.00**
0.00	1.00	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91
0.10	0.90	0.90	0.89	0.88	0.87	0.86	0.85	0.84	0.84	0.83
0.20	0.81	0.81	0.80	0.79	0.79	0.78	0.77	0.76	0.76	0.75
0.30	0.74	0.73	0.73	0.72	0.71	0.70	0.70	0.69	0.68	0.68
0.40	0.67	0.66	0.66	0.65	0.64	0.64	0.63	0.63	0.62	0.61
0.50	0.61	0.60	0.59	0.59	0.58	0.58	0.57	0.57	0.56	0.55
0.60	0.55	0.54	0.54	0.53	0.53	0.52	0.52	0.51	0.51	0.50
0.70	0.50	0.49	0.49	0.48	0.48	0.47	0.47	0.46	0.46	0.45
0.80	0.45	0.44	0.44	0.44	0.43	0.43	0.42	0.42	0.41	0.41
0.90	0.41	0.40	0.40	0.39	0.39	0.39	0.38	0.38	0.38	0.37

Similarly, for $SDR = \exp^{(-k\,S\,L)}$ described in chapter IV, mainly when the flow length increases, the product value of K, S and L tend to increase. But when "–" (negative) sign and base e value were taken into consideration, the value of SDR decreases and tends to near "0". However, when the product value reaches near to "0", the SDR value increases tends to "1". This is the reason why the value of SDR is greater down slope near watershed outlet as it was found in chapter V.

CURRICULUM VITAE

Mr. Ugyen Thinley was born on May 05, 1976 in Guyum under Pemagatshel district, Bhutan. He received his Bachelor's Degree in Science in 2001 from Sherubtse College affiliated to Delhi University. After graduation, he was employed erstwhile in Department of Survey and Land Records, Ministry of Agriculture, Thimphu. In the same year, he was sent to Hyderabad, India for undergoing surveying engineering course. In 2003, he completed engineering and since then worked as Surveying Engineer in National Land Commission of Bhutan prior to his completion of M. Sc. degree in Geo-informatics from Suranaree University of Technology, Nakhon Ratchasima, Thailand.