

**INTEGRATED LAND USE CHANGE ANALYSIS FOR SOIL EROSION STUDY
IN ULU KINTA CATCHMENT**

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LIST OF ABBREVIATIONS

ANSWERS	areal non-point source watershed environment response simulation
DEM	Digital Elevation Model
DN	Digital Number
EUROSEM	European soil erosion model
GCP	Ground Control Point
GIS	Geographic Information System
GPS	Global Positioning System
ISODATA	Iterative Organising Data Analysis
MACRES	Malaysian Center for Remote Sensing
MSS	Multi-spectral Scanner
NDVI	Normalised Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
PCA	Principal Component Analysis
PERFECT	productivity erosion runoff functions to evaluate conservation techniques
PFE	Permanent Forest Estate
RMSE	Root Mean Square Error
RSO	Rectified Skew orthomorphic
RUSLE	Revised universal Soil Loss Equation
SPOT	System Pour l'Observation de la Terra
TM	Thematic Mapper
UTM	Universal Transverse Mercator
WEPP	Water erosion prediction project

INTEGRATED LAND USE CHANGE ANALYSIS FOR SOIL EROSION STUDY IN ULU KINTA CATCHMENT

ABSTRACT

Ulu Kinta catchment has experienced rapid changes in land use and land cover from 1991 to 2004. These changes have resulted in increased upland erosion and higher concentrations of suspended sediment within the catchment. The goal of this research was to investigate the application of integrated satellite remote sensing and Geographic Information Systems (GIS) techniques to assess land cover changes and the estimation of soil erosion in the water catchment. Inherent in this research was the interpretation of multi-sensor data collected by several satellite systems, evaluation of the quality of the resulting change information, application of remotely sensing and other ancillary data as input in GIS-based RUSLE model to analyse soil erosion process induced by different land cover changes. Change detection was performed using post-classification comparison method which produced acceptable results, overall accuracy 61.4 % and kappa = 56 %. The study revealed that while the estimated mean annual soil loss rate was approximately 16.2 tons/ha/yr and 52 tons/ha/yr for 1991 and 2004 respectively, soil loss rate as high as 172.0 tons/hr/yr were found on sloping lands from Ulu Kinta catchment. A good correlation of $r^2 = 0.9169$ was obtained between modeled annual average soil loss estimation and annual average sediment loads obtained at site. Results of the study indicate that land use changes in the study area have produced environmental problems such as water pollution and soil erosion. In this research, a comprehensive methodology was developed to collect representative data quickly and simply, showing that in a GIS environment the RUSLE model can be applied to determine field-scale soil loss quantitatively and spatially, to predict erosion hazard over given watershed. The study indicates that the RUSLE-GIS model is useful tool for resource management and soil conservation planning.

Analysis Perubahan Guna Tanah Secara Bersepadu untuk Kajian Hakisan Tanah di Kawasan Tadahan Ulu Kinta

ABSTRAK

Kawasan tadahan Ulu Kinta telah mengalami perubahan yang ketara di dalam penggunaan tanah dan liputan tanah dari tahun 1991 hingga 2004. Perubahan ini telah meningkatkan hakisan tanah dan meninggikan kepekatan bahan asing yang terampai di dalam kawasan tadahan. Tujuan kajian ini adalah untuk mengkaji penggunaan bersama teknik penderiaan jauh satelit dan Sistem Maklumat Geografi (GIS) untuk menilai perubahan liputan bumi dan anggaran penghakisan tanah untuk kawasan tadahan air. Kajian ini juga menggunakan data pelbagai satelit untuk mengkaji kualiti maklumat perubahan guna tanah, penggunaan data penderiaan jauh dan data rujukan lain sebagai input dalam model RUSLE yang berdasarkan GIS untuk menganalisa proses penghakisan tanah yang disebabkan oleh perubahan liputan bumi yang berbeza. Pengenalpastian perubahan telah dilakukan dengan menggunakan kaedah perbandingan pasca pengelasan yang telah menghasilkan keputusan yang boleh diterima, iaitu ketepatan keseluruhan 61.4% dan kappa = 56%. Kajian telah menunjukkan purata kadar kehilangan tanah yang dijangka adalah lebih kurang 16.2 ton/hektar/tahun dan 52 ton/hektar/tahun pada tahun 1991 dan 2004, kadar kehilangan tanah setinggi 172.0 ton/hektar/tahun telah dikesan pada tanah cerun di kawasan tadahan Ulu Kinta. Perbandingan yang baik diperolehi, iaitu $r^2 = 0.9169$ telah diperolehi daripada keputusan model purata tahunan kehilangan tanah dengan data purata tahunan beban endapan di tapak. Keputusan daripada kajian menunjukkan perubahan penggunaan tanah dalam kawasan kajian telah menyebabkan masalah persekitaran seperti pencemaran air dan hakisan tanah. Dalam kajian ini, satu metodologi yang komprehensif telah dibangunkan untuk mengumpul data perwakilan secara cepat dan mudah, menunjukkan bahawa dalam persekitaran GIS model RUSLE boleh digunakan untuk menentukan kehilangan tanah pada skala kawasan secara kuantitatif dan ruang. Kajian ini boleh menjangkakan bahaya kehakisan pada kawasan tadahan air yang diberi. Kajian juga menunjukkan model RUSLE-GIS sebagai satu alat yang berguna untuk pengurusan sumber dan pelan pemuliharaan tanah.

CHAPTER ONE

INTRODUCTION

1.1 Background

Soil erosion is the major threat, among others, to the conservation of the soil and water resources. Even though soil erosion can be caused by geomorphological processes, anthropological or accelerated erosion, which is mainly favored by human activities, is the major trigger factor for the loss of soil and water resources. Soil erosion has accelerated on most of the world, especially in developing countries, due to different socio-economic, demographic factors and limited resources (Ni and Li, 2003). For instance, De Roo (1996) mentioned that increasing population, deforestation, land cultivation, uncontrolled grazing and higher demand for fire often cause soil erosion.

Change produced by human action on the landscape can have a strong impact upon water resources both in terms of their quantity and their quality. These hydrological changes may influence overland flow, soil erosion, streamflow and sediment transport. A lot of recent research in these hydrological processes had shown that it is now possible to model the process change resulting from the impacts of land use. Results indicate that some parts of the watershed are more sensitive to a particular type of land use change than others (Mo and Zhou, 2000). In particular it is thought that the 'contributing' areas closest to fluvial zones are extremely sensitive and that, if left undisturbed, these areas can act as a barrier to hydrological impact (Famiglietti and Wood, 1991).

The impact on land use and land cover changes, especially in terms of changes from forest cover to other land cover, has been one of the important issues on land use change research. In primitive times when there was little human population and low level of economic activity, deforestation was not a problem because the

natural regeneration of forest was adequate to cover for any loss of forest by the human beings.

In Malaysia, land use has undergone many changes particularly after the country achieved its independence. Land use changes were driven by a number of economical, socio-political and biophysical factors. Over the last two decades, the evolution of land use became drastic in the urban and rural areas. Especially, more land areas have been displaced or converted to non-agricultural activities particularly for industry, housing and commercial activities (Hashim et al., 1995). Land use and land cover are continuously changing, both under the influence of human activities and nature resulting in various kinds of impacts on the ecosystem. In fact, FAO (2003) noted that land use impacts have the potential to significantly affect the sustainability of the agricultural and forest systems.

Digital land use and land cover change detection is the process of determining and/or describing changes in land-cover and land-use properties based on co-registered multi-temporal remote sensing data. The basic premise in using remote sensing data for change detection is that the process can identify change between two (or more) dates that is uncharacteristic of normal variation. To be effective, change detection approaches must maximize inter-date variance in both spectral and spatial domains (i.e. using vegetation indices and texture variables). Numerous researchers have addressed the problem of accurately monitoring land-cover and land-use change in a wide variety of environments with a high degree of success (Muchoney and Haack, 1994; Chan et al., 2001).

The simplest taxonomy separates land-cover and land-use changes that are *categorical* versus those that are continuous (Abuelgasim et al., 1999). Categorical changes in time, also known as post-classification comparison, occur between a suite

of thematic land-cover and land-use categories (e.g. urban, developed, grassland, forest). Post-classification change detection techniques, however, have significant limitations because the comparison of land-cover classifications for different dates does not allow the detection of subtle changes within land-cover categories (Macloed and Congalton, 1998). Further, the change-map product of two classifications often exhibits accuracies similar to the product of multiplying the accuracies of each individual classification (Mas, 1999).

The second category of change is continuous, known also as pre-classification enhancement, where changes occur in the amount or concentration of some attribute of the urban/suburban or natural landscape that can be continuously measured (Coppin and Bauer, 1996). The goal of change detection in a continuous context, therefore, is to measure the degree of change in an amount or concentration of a variable such as vegetative or urban cover, through time.

Once the choice of change detection taxonomy is determined, decisions on the data processing requirements can be made. Requirements include geometric/radiometric corrections, data normalization, change enhancement, image classification and accuracy assessment (Lunetta and Elvidge, 1998).

1.2 Main Focus Areas of this Study

The main aim of this research is to investigate the application of an integrated land use change for soil erosion. Different techniques for analyzing remotely sensed data acquired by different optical sensors, specifically focusing on their application to land use and lands cover change and soil erosion.

During the last three decades, a large number of change detection methods have evolved that differ widely in refinement, robustness, and

complexity. However many of these methods rely upon the evaluation of combined datasets derived from multiple epochs. These include principal component analysis (PCA), tasselled-cap analysis, combined classification techniques and image differencing techniques (Jensen, 1996). The basis of these approaches is the consistent spatial, spectral and radiometric qualities of the data resulting from sensing with an instrument of similar specification. Where dissimilar sensors are utilised, substantial differences-exist in all sensor specifications, in particular spatial and spectral resolution and the above combined approaches are no longer appropriate (Campbell, 2002).

Due to considerable differences in the spectral, spatial and radiometric characteristics of the data, analysis must involve separate interpretation of each dataset. Within this context, post-classification analysis is appropriate for evaluation of land cover changes from data of different sources.

Rectification process of multi-date data has been identified as essential for all change detection purposes. Registration errors directly affect any assessment of land cover change and result in many areas of false change recorded in change detection statistics. Comparison of multiple remote sensing data further complicates the process because each dataset contains errors of location inherent to the sensing system. Classification errors contributed by the interpretation approach and spatial errors due to the spatial resolution of the sensor and the sampling interval adopted during rectification are also important. Modelling and evaluation of these errors is necessary in order to assess the reliability of change detection statistics derived from multiple satellite data (Richards, 1994).

The use of remotely sensed data in the study of environmental changes is substantial. Remotely sensed data can be used to develop comprehensive digital

databases for any target area to study different environmental issues and parameterize environmental models (Foody and Curran, 1994). One of the most destructive processes, steadily increasing as a result of human activity in these areas, is soil erosion (Lal, 1988). This raises many concerns regarding the potentially damaging impacts of contemporary land use in relation to the often weak or non-existent land management initiatives. Malaysia is one country suffering heavily from land degradation due to increasing anthropogenic pressure on its natural resources (Roslan et al., 1997). As economic activity and population increased, in many parts of Malaysia agriculture, built-up areas and infrastructure development spread rapidly to the uplands. Consequently, the problem of soil erosion and degradation, sedimentation and river pollution increased (Hashim et al., 1995; Bawahidi et al., 2004).

The research also covers most important aspects of remote sensing and GIS techniques. Given multi-source remotely sensed data, there is an increasing need for improved techniques to extract variety of information from the data. Moreover, new satellite sensors are now providing a huge amount of time series data for environmental monitoring.

Major issues involved in change detection using remote sensing data including geometric correction, radiometric correction or normalization, change enhancement and detection, and classification for land-cover and land-use monitoring, catchment characterization and soil erosion estimation.

From the discussion above, it is believed that the recent advances in remote sensing data acquisition and management of spatial geographic data would benefit catchment characterization and soil erosion models that use spatial data inputs. Therefore, the principal aim of this research would be to evaluate the value of

incorporation of remote sensing and GIS techniques in estimating land use change and soil erosion and its impact to water resources.

1.3 Main Research Objectives

In this research the spatial properties of land use/ land cover and soil parameters were investigated where their contribution to soil loss can be appraised. To evaluate the value of this contribution the following research objectives were determined:

- To examine the main problems in land-cover classification of using pixel-based classifiers based on multi-source data, and provide potential solutions to these problems, using pixel-based classifiers, and evaluate their effectiveness.
- To investigate the application of change detection techniques to multi-source remote sensing data. Spectral and spatial properties of the data are investigated in order to evaluate the potential of change detection using different satellite sensors. The classification accuracy of each sensor is evaluated against known land cover distributions derived from land cover maps of Kinta District. The contribution of thematic and spatial errors caused by sensor sampling and geometric registration is also evaluated. An analysis of the thematic and spatial accuracy of the final land cover change detection image is also completed.
- To develop a methodology that combines remote sensing data and GIS with Revised Universal Soil Loss Equation (RUSLE) to estimate the spatial distribution of soil erosion at catchment scale.

1.4 Methodology and Main Research Tasks

The current study was carried out for Ulu Kinta catchment and designed to investigate the potential to utilise remotely sensed data from sensors with different spatial and spectral resolutions for temporal assessment of land cover changes and its

effects on soil erosion in the Ulu Kinta catchment. An assessment of the suitability of the approach is based upon an evaluation of the classification accuracy and consistency of the data derived from various sensors, and the contribution to the results of the geometric properties of the sensor and the geocoding method applied. The sources of satellite information used for this research are Landsat TM, SPOT HRV multi-spectral data and SPOT panchromatic data. The datasets are utilised for thematic classification, geometric assessment, derivation of catchment characteristics and topographic parameters for soil erosion modeling.

In this research the following tasks will be implemented:

- (i) Review the use of remote sensing for information extraction applied to temporal assessment, focusing on the spectral and spatial resolutions of satellite sensors and how these affect image interpretation. Classification accuracy and change detection reporting will also be evaluated;
- (ii) Compile relevant Landsat TM, SPOT HRV and SPOT panchromatic satellite data for the study area in a format suitable for analysis. Prepare topographic, land use, soil maps for use as reference data and for developing digital elevation model ;
- (iii) Adapt land use and land cover classification system suitable for the study area based upon a standard classification system for Peninsular Malaysia and considering the spectral and spatial resolutions of the satellite data. Assess the accuracy of each classification of remotely sensed imagery;
- (iv) Define the land cover changes and evaluate change representation for the satellite data by analysing the change matrices and their accuracy parameters;
- (v) Develop an appropriate and up-to-date catchment database which includes spatial and attribute data and integrated use of digital elevation data for modeling and management of natural resources;

- (vi) Model the spatial distribution of soil erosion using Revised Universal Soil Loss Equation (RUSLE) in a GIS with multi-source data.

A typical implementation procedure for remote sensing data processing and extraction of RUSLE factors is shown in Fig.1.1 and Fig.1.2.

1.5 Significance and Potential Contribution

This study provides an image processing and change assessment approach that can be applied to land cover change analysis using multi-source satellite data. Evaluation of the reliability of the multi-source approach to change detection provides future users with an alternative to the standard temporal assessment methods, and enables digital data from different sensors to be interpreted for derivation of land cover change statistics. This will overcome limitations on the assessment of change caused by current approaches, which rely upon analysis of digital data from the same remote sensing system. The flexibility afforded will enable users to access a combination of data sources, especially where weather conditions and reception facilities may restrict access to regular monitoring information.

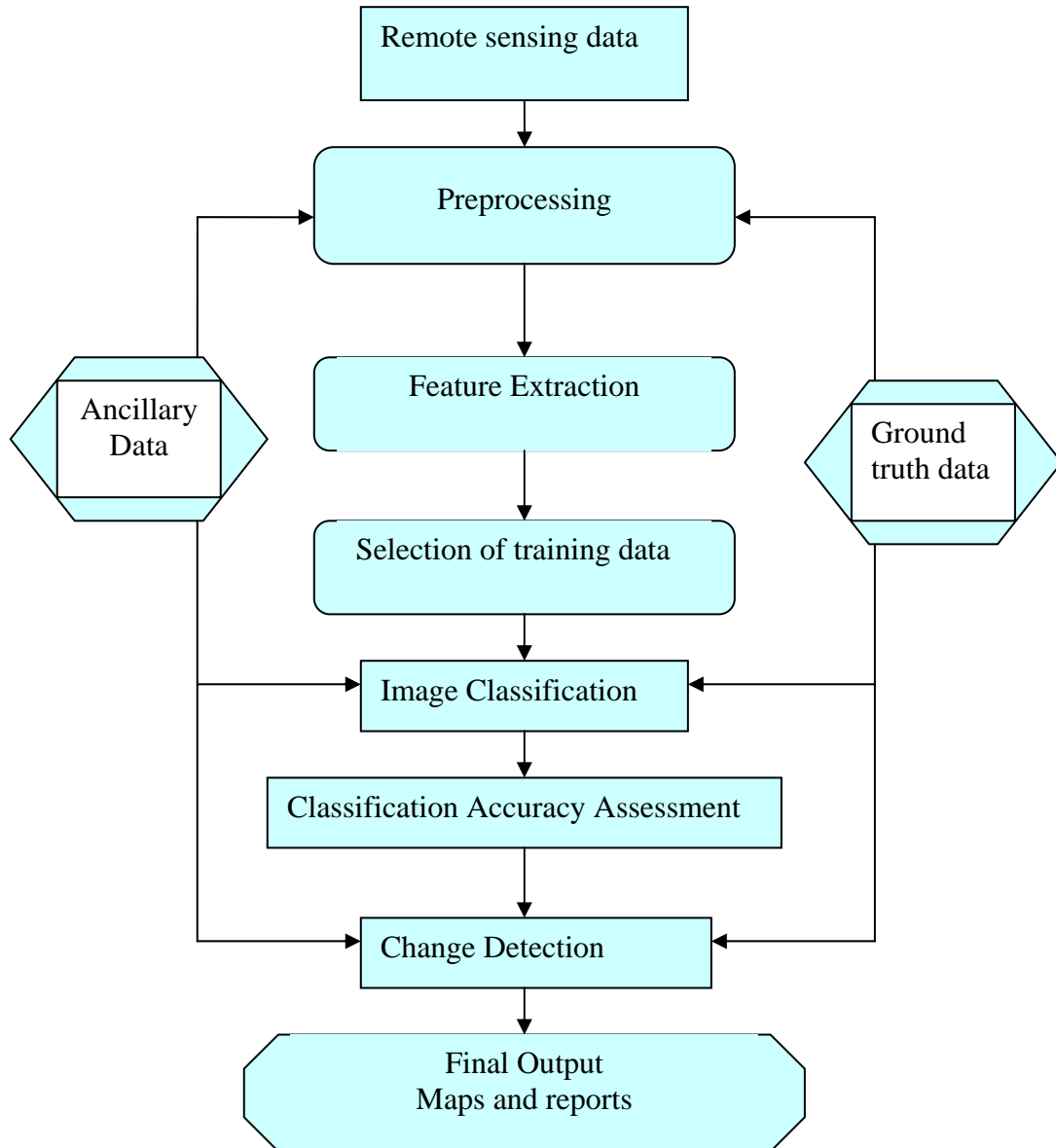


Fig. 1.1 A flowchart of procedure for deriving land use/land cover data and change detection from remotely sensed data.

The main contributions of this research are to better understand the complex interplay of land-use changes and their effects on soil loss rates in a water catchment and contribute to current knowledge of the effects of land-use and land cover changes on soil erosion. It would also demonstrate the effectiveness of the integrated approach in predicting the long-term impacts of future land use changes.

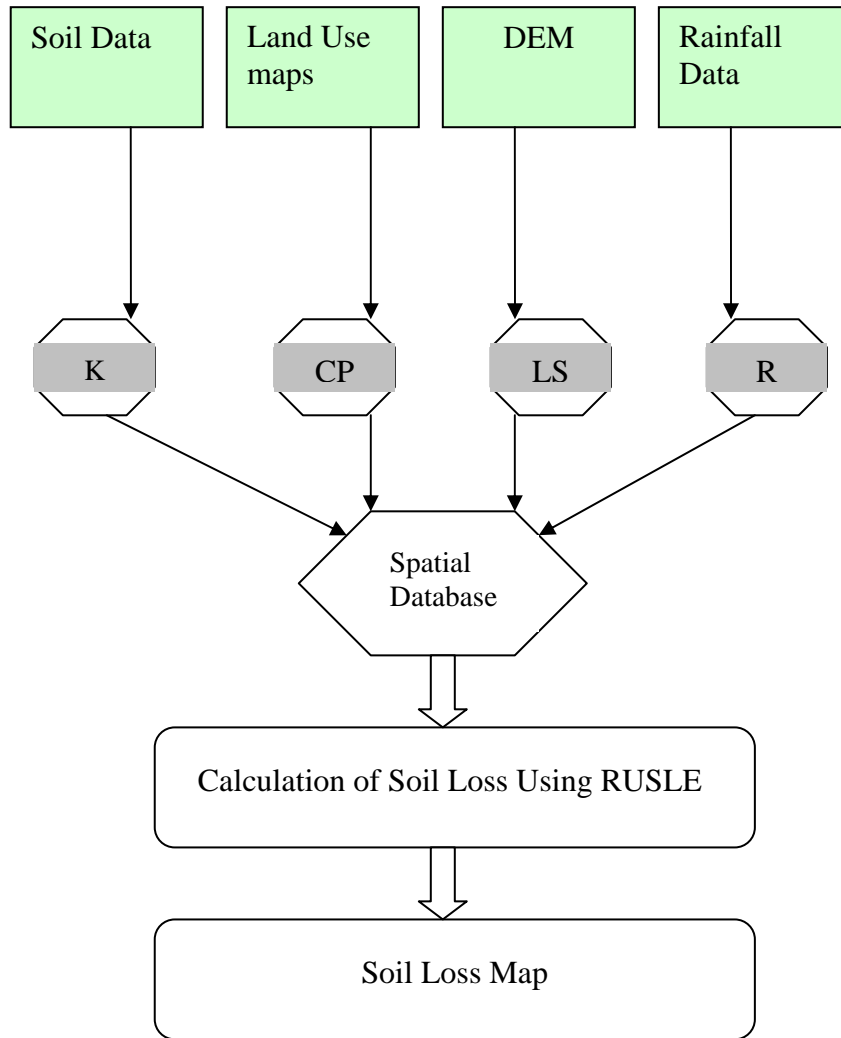


Fig.1.2 The procedure for extraction of RUSLE factors from remote sensing and ancillary data.

1.6 Organization of Thesis

In Chapter 2, a general review of land use and land cover change detection using remotely sensed data is presented. The chapter considers also the importance of soil erosion under distinct land use/ land cover conditions. The role of remote sensing and GIS approach integrated with soil erosion models is outlined.

Chapter 3 presents the study area and describes the physical characteristics of the area to be analysed. This Chapter also provides a detailed description of the remotely sensed data used, namely Landsat TM data, SPOT multispectral (SPOT XS) data, and SPOT panchromatic data, along with the important characteristics of the sensors which are relevant to change detection analysis. Preprocessing of the data prior to analysis is also outlined.

Satellite image preprocessing, rectification and resampling are detailed in Chapter 4. This Chapter describes the available techniques for image rectification and outlines relevant factors to be considered in ground control point (GCP) selection. Resampling schemes are also considered and discussed with respect to establishing a common spatial resolution for the Landsat TM and SPOT data and maintenance of a spectrally coherent dataset. The spatial effects of image resampling are investigated and the precision of the rectified images is evaluated. Land use classification strategies in the context of their application to multi-source analysis are reviewed in this Chapter also. The process of image classification is described and applied to the study area for each data set. Detailed analysis of the spectral separability of land cover is performed. Results of the classification of each image using supervised and unsupervised classification techniques are presented. The role of the DEM and textural data in improving spectral classification is considered.

Chapter 5 reviews thematic mapping accuracy assessment methods and assessment made of the classification performance for each resolution of satellite data. Overall Classification Accuracy and Kappa Coefficient statistics are derived, and the optimum classification approach for each level of classification and for each image dataset is determined. Land use change detection techniques are reviewed in Chapter 5 also. The post-classification comparison approach is used to derive land cover change maps between 1991 and 2004. Summary statistics of change are

produced using change matrices and the land cover changes between dates are investigated. The effectiveness of change detection techniques using different data is evaluated and the concept of change reporting as a means of measuring and communicating changes identified using remote sensing is considered.

Detailed approaches to study Ulu Kinta catchment is presented in Chapter 6. The general and current approaches for the integration of remote sensing and GIS for the catchment are presented. The Chapter reviews the entire process of developing catchment database using different spatial data and derive GIS coverages needed for estimating soil erosion. The temporal results of spatial distribution of soil loss change from 1991 to 2004 are presented and analysed.

Results of the whole research study carried out in Ulu Kinta River Basin are presented in Chapter 7

In Chapter 8 the conclusions and recommendations for future research regarding land use change detection and soil loss issues are given.

CHAPTER TWO

LITERATURE REVIEW: THEORETICAL BACKGROUND

2.1 Introduction

Remote sensing is defined as the science of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand et al., 2004). Since the launch of Landsat-1 – the first Earth resource satellite in 1972, remote sensing has become an increasingly important tool for the inventory, monitoring, and management of earth resources. The increasing availability of information products generated from satellite imagery data has added greatly to our ability to understand the patterns and dynamics of the earth resource systems at all scales of inquiry.

A particularly important application of remote sensing is the generation of land use/ land-cover maps from satellite imagery. Compared to more traditional mapping approaches such as terrestrial survey and basic aerial photo-interpretation, land-use mapping using satellite imagery has the advantages of low cost, large area coverage, repetitively, and computability (Franklin, 2001). Consequently, land-use information products obtained from satellite imagery such as land-use maps, data and GIS layers have become an essential tool in many operational programs involving land resource management.

The prospect for the use of satellite imagery data in land-use management and planning is an extremely promising one. As a result of the recent development of sensor technology, the quality of satellite imagery available for land-use mapping is improving rapidly. Particularly noteworthy in this regard is the improved spatial and spectral resolution of the imagery captured by new satellite sensors. The use of

imagery from high-resolution sensors on satellites such as IKONOS and QuickBird has proved that data from space-borne sensors can provide a viable alternative to aerial photography in many applications including detailed land cover mapping, water resources assessment, irrigation management and, crop and yield mapping (Shamshad et al., 2004; Lillesand et al., 2004; Mesev et al., Trietz and Rogan, 2004).

The increasing availability of satellite imagery with significantly improved spectral and spatial resolution has offered greater potential for more detailed land-use mapping. It was predicted that in the near future, more than 50 percent of the current aerial photo market will be replaced by high-resolution satellite imagery (Fritz, 1996). At the same time, rapid advances in the computer science as well as other information technology (IT) fields have offered more powerful tools for satellite image processing and analysis. Image processing software and hardware are becoming more efficient and less expensive. Access to faster and more capable computer platforms has aided our ability to store and process larger and more detailed image and attributes data sets.

Digital image processing involves manipulation and interpretation digital images with the aid of computer technology. Recently, digital image processing is central to efficient use of satellite imagery in land-use studies. A key task of satellite image processing is to develop image data analysis approaches appropriate to a particular resource management application (Treitz and Rogan, 2004). The extraction and classification of land-cover types from satellite imagery is probably the most important objective of digital image analysis in the geoscience. Conventional image classification techniques are based on the spectral response patterns of terrain features captured in satellite imagery (Taib, 1997). While conventional spectral classifiers are widely used and have achieved a fairly large amount of success, the resulting classification maps are often very noisy.

The enhanced information content of high-resolution satellite imagery and the long-term desire of land-use planners to obtain detailed land-use maps highlight the need for more powerful tools for analyzing multi-spectral data. As a result in recent years it was seen a multiplicity of approaches to satellite image classification had developed. A main thrust in this development is that, in addition to making better use of enhanced spectral information of imagery data, increasing attention is being given to the spatial and semantical characteristics of terrain features (Dorren, 2003). Recent studies demonstrated that the higher information content of imagery data combined with the improvements in image processing power result in significant improvement in classification accuracy (Liu and Zhou, 2004; Munchney and Strahler, 2002; Cihlar and Jansen, 2001; Congalton and Green, 1999)

2.2 Remote Sensing in Land Use/ Land Cover Change

Land cover as defined by Barnsley et al, (2001) is "the physical materials on the surface of a given parcel of land (e.g. grass, concrete, tarmac, water)," and land use as "the human activity that takes place on, or makes use of that land (e.g. residential, commercial, industrial)". Land use can consist of varied land covers, (i.e. a mosaic of biogeophysical materials found on the land surface). For instance, a single-family residential area consists of a pattern of land-cover materials (e.g. grass, pavement, shingled rooftops, trees, etc.). The aggregate of these surfaces and their prescribed designations (e.g. park) determines land-use (Anderson et al., 1976).

Land-use is an abstract concept, constituting a mix of social, cultural, economic and policy factors, which have little physical importance with respect to reflectance properties, and hence has a limited relationship to remote sensing. Remote sensing data record the spectral properties of surface materials, and hence, are more closely related to land-cover. In short, land use cannot be measured directly by remote sensing, but rather requires visual interpretation or sophisticated image processing and

spatial pattern analyses to derive land use from aggregate land-cover information and other ancillary data (Cihlar and Jansen, 2001). Integrated analyses within a spatial database framework (i.e. GIS) are often required to assign land cover to appropriate land-use designations (Noordin, 1997).

Success in land-cover and land-use change analysis using multi-temporal remote sensing data is dependent on accurate radiometric and geometric rectification (Schott et al., 1988; Dai and Khorram, 1999). These pre-processing requirements typically present the most challenging aspects of change detection studies and are the most often neglected, particularly with regard to accurate and precise radiometric and atmospheric correction (Chavez, 1996). For change to be identified with confidence between successive dates, a consistent atmosphere between dates must be modeled so that variations in atmospheric depth (i.e. visibility) do not influence surface reflectance to the extent that land-cover change is detected erroneously. This is particularly important in biophysical remote sensing where researchers attempt to estimate rates of primary productivity and change in total above ground biomass (Coppin and Bauer, 1996; Treitz and Howarth, 2000; Franklin, 2001; Peddle et al., 2003). Where change is dramatic, (i.e. conversion of agricultural land to residential), the 'change signal' is generally large compared to the atmospheric signal. Here, the accuracy and precision of geometric registration influences the amount of spurious change identified. Where accurate and precise registration of one date to the other is achieved, identified surface changes can be confidently attributed to land conversion. Inaccuracy and imprecise co-registration can lead to systematic overestimation of change, although methods have been developed to compensate for these effects (e.g. spatial reduction filtering).

Research continues to focus on the potential for digital image processing of high-resolution imagery for detecting, identifying and mapping areas of rapid change

(Longley et al., 2001). It has been noted that the utility of per-pixel classification of spectral reflectance for identifying areas of land modification, or land conversion is limited, as a result of various sources of error or uncertainty that are present in areas of significant landscape heterogeneity (e.g. rural–urban fringe, forest silvicultural thinning, etc.). For urban areas, the complex mosaic of reflectance creates significant confusion between land-use classes that possess reflectance characteristics similar to those of land-cover types.

Typically, the quality (i.e. precision and accuracy) of automated per-pixel classifications in urban areas using remote sensing are poor, compared to non-urban areas. Also, urban areas present the problem of having logical correspondence between spectral classes and functional land-use classes (Treitz and Howarth, 2000). Improvements in traditional per-pixel classifications have been developed over the last decade and include (i) the extraction and use of *a priori* probabilities or *a posteriori* processing (Barnsley, 1999; Mesev et al., 2001); (ii) texture processing (Haralick, 1979; Barnsley et al., 2001); (iii) artificial neural networks (Abuelgasim et al., 1999); (iv) fuzzy set theory (Foody, 1996; Zang and Foody, 1998); (v) frequency-based contextual approaches (Gong et al., 1992); (vi) knowledge-based algorithms (Wang and Zhang, 2000; Mariamni, 1997; Huang and Jensen, 1997); (vii) image segmentation (Connors et al., 1984; Bähr, 2001); and the incorporation of ancillary data (Harris and Ventura, 1995; Treitz and Howarth, 2000). These approaches are necessary to accommodate the more complex spatial structures arising from heterogeneous spectral signatures, particularly in urban environments, but also for fragmented and heterogeneous canopies common in areas of secondary growth and human influence.

Research into sophisticated spatial analytical methods for land-cover and land-use classification continues through the integration of land-use morphology regarding configuration, syntax, structure, and function with the inherent characteristics of remote

sensing data (Curran et al., 1998; Barnsley, 1999; Longley et al., 2001). For urban areas, research has focused on (i) empirical/statistical kernel-based techniques (Wharton, 1987) (ii) knowledge-based texture models (i.e. relating spatial variations in detected spectral response to dominant land-use, using explicit spatial models of urban structure as opposed to empirical models) (Barnsley et al., 2001); and (iii) structural pattern-recognition techniques (Barnsley, 1999). It remains difficult to map point and linear features, particularly digitally, due to the fact that they are not always recognizable at the spatial resolution of the data, nor are they represented at their 'true' location due to sensor and panoramic distortions inherent in satellite data collection.

It has also proven difficult to digitally separate linear features such as road networks from surrounding land-cover and land-use or mixed vegetation in high mountainous areas (Wang and Zhang, 2000). This is largely due to the complexity of pattern recognition procedures required for tracing specific cultural edge features. In a previous study at mapping of land use and land cover on mountainous area, Baban and Yusof (2001), utilized Landsat TM bands TM3, TM4, and TM5 incorporated with ancillary topographic data as input to maximum likelihood classifier to produce land cover map of hilly area in Langkawi Island. The overall accuracy of output image was 90% and individual class accuracies ranged from 74% to 100%. Their results highlight the important of incorporation of topographic data and indicate that the topography is the main control on spatial distribution of land use/ land cover types in the study area.

2.3 GIS in Watershed and Soil Erosion Research

Spatially distributed models of watershed hydrological processes have been developed to incorporate the spatial patterns of terrain, soils, and vegetation as estimated with the use of remote sensing and geographic information systems (GIS) (Band, 1986; Noordin, 1994; Famiglietti and Wood, 1991 and 1994; Moore et al., 1988; Moore et al., 1991). This approach makes use of various algorithms to extract and

represent watershed structure from digital elevation data. Land surfaces attributes are mapped into the watershed structure as estimated directly from remote sensing imagery (e.g. canopy leaf area index), digital terrain data (slope, aspect, contributing drainage area) or from digitized soil maps, such as soil texture or hydraulic conductivity assigned by soil series.

2.4 Digital Elevation Models (DEM)

A digital elevation model (DEM) is a type of spatial data set, which describes the elevation of the land surface. The height and form of terrain have a fundamental influence on most environmental phenomena. Consequently, DEMs are widely used in environmental applications of GIS (Moore et al., 1991). Information about the terrain surface plays a key role in nearly all environmental research including hydrology, geomorphology, ecology and other disciplines (Garbrecht and Martz, 1993). Therefore a DEM is a fundamental requirement for many GIS applications, both directly due to the influence of elevation on many environmental phenomena and indirectly due to the influence of variables derived from a DEM such as gradient and aspect on environmental phenomena and processes (Fahsi et al., 2000).

2.4.1 Data Sources for Generating DEM

Data for DEMs should be observations of the elevation and the shape of terrain surface with particular attention to surface discontinuities and special locations (passes, pits, peaks, ridges etc.). These data can be acquired using different methods: ground survey, photogrammetry using aerial photographs or satellite imagery, digitizing the contour lines on topographic maps (Martz and Garbrecht, 1998).

2.4.2.1 Ground Surveys

Ground surveys can provide a very accurate DEM data because surveyors usually tend to capture the elevation of discontinuities and special location that are

characteristic for the area under observation. However, it is relatively time consuming and therefore is usually applied to specific projects which involve small study areas. The advent and widespread use of Global Positioning System (GPS) provides many new and affordable opportunities for the collection of large numbers of special-purpose elevation data sets (Blaschke and Stroble, 2001).

2.4.2.2 Photogrammetric Data Capture

These sources rely on the stereoscopic interpretation of aerial photographs or satellite imagery using manual or automatic stereoplotters (Campbell, 2002). Using stereoscopic aerial photographs or stereoscopic SPOT images and suitable equipment, it is possible to collect elevation data using different sampling methods.

2.4.2.3 Digitizing existing maps

Digitization of contour lines on topographic maps is an adequate method for DEM creation in areas of very rough terrain (Martz and Garbrecht, 1998). Once the point surface has been created, an interpolation algorithm is applied to interpolate elevation values for unknown or unsampled areas based on the "known" elevation values. The accuracy of DEM generated from data captured using such techniques depends on the quality and scale of original source maps (Singh and Fiorentino, 1996)

Over the past decade numerous approaches have been developed for automated extraction of watershed structure from grid digital elevation models (e.g. Mark et al., 1984; O' Callaghan and Mark, 1984; Band, 1986; Jenson and Dominique, 1988; Moore and Burch, 1986; Martz and Garbrecht, 1993; Garbrecht and Martz, 1993). O' Callaghan and Mark (1984) define a digital elevation model (DEM) as any numerical representation of the elevation of all or part of a planetary surface, given as a function of geographic location. The most widely used method for the extraction of stream networks that has emerged is to accumulate the contributing area upslope of

each pixel through a tree or network of cell to cell drainage paths and then prune the tree to a finite extent based on a threshold drainage area required to define a channel or to seek local morphological evidence in the terrain model that a channel or valley exists (Moore and Burch, 1986).

In more recent studies important efforts were made to implement digital satellite data have utilized higher spatial, spectral, and radiometric resolution Landsat Thematic Mapper (TM) data with much more powerful computer hardware and software (Setiawan et al., 2004; Omar et al., 2004). These studies have shown that the higher information content of TM data combined with the improvements in image processing power result in significant improvements in image processing power resulting in significant enhancement in classification accuracy for more distinctive classes.

2.5 Soil Erosion in Malaysia

Similar to most of the other developing countries, Malaysia is characterised by a rapid pace of development over the last three decades in agriculture, industry, tourism, building of highways and dams. All these activities resulted in clearing of large forest areas, destruction of water resources and destabilization of hill slopes which lead to other environmental hazards such as soil loss and landslides (Omar et al., 2004).

The major changes in land use have been instigated by the desire to meet the food requirements of the population, to provide large quantities of raw materials for export and to support the agro-based industries. Being a country with vast natural resources, Malaysia has presently opted for the exploitation and export of natural resource products to meet the demands for better lifestyle and the challenges of exponential population growth (Maene and Suliman, 1986; Hashim et al., 1995).

A significant amount of effort has been made in the past to quantify the erosion risk, and rate of soil erosion, of catchment areas exhibiting different land uses changes and the sedimentation/siltation rate of rivers draining forested, agricultural dominated and urbanizing catchments. Both direct and indirect methods of prediction have been applied. Direct measurements of erosion rates have been carried out on relatively small agricultural plots; and on specific construction sites including road development areas. These have been conducted in Malaysia as well as in other countries; especially in the United States of America (Lal, 1988).

In Peninsular Malaysia, numerous instances of soil erosion have been documented, mainly in association with timber extraction, mining activities, agricultural and urban expansion. However, few quantitative measurements of soil erosion have been made and most data available are derived from studies of sediment concentration in rivers (Maene and Suliman, 1986). Morgan pointed out that much of the sediment removed from hillsides is deposited before it reaches the rivers and therefore, data on sediment concentration in rivers almost certainly underestimate the rates of soil loss.

In the recent years there is a general awareness of soil erosion as an environmental problem in Malaysia. The literature documented some researches toward the analysis and estimating of soil loss rates using integrated remote sensing and GIS approaches with USLE. These include the soil erosion study of the Bakun Dam project (Samad and Abdul Patah, 1997) and soil erosion risk assessment for Genting Highlands (Jusoff and Chew, 1998). Other studies were directed to estimate the soil loss using different modeling approaches. In a study conducted in the east coast of Peninsular Malaysia using the process-based model GUEST (Griffith University Erosion System Template). Hashim et al. (1995) showed that soil loss and runoff were particularly high where the pathways were very pronounced. Their results show that the major factors effecting soil erosion are surface cover management,

amount of runoff generated, its rate and, the condition of the soil surface. Ramli et al. (2004) used open source (GRASS) to assess the erosion hazard in Langkawi Island. This study demonstrates the effectiveness of the GRASS in generating quantitative information on soil erosion studies. The results predicted that about 98 percent of the Langkawi has very low to low erosion risk and only 2 percent of the island is of moderate to high erosion risk.

Soil erosion models can be used for farm planning, site-specific assessment, project evaluation and planning, policy decisions or as research tools to study processes and the behavior of hydrologic and erosion systems. There have been numerous models (both empirical and process-based) developed in the past to predict both runoff and soil loss at a field or catchment level. The models vary from very complex procedures requiring a range of input parameters (e.g., water erosion prediction project (WEPP), European soil erosion model (EUROSEM) and aerial non-point source watershed environment response simulation (ANSWERS), to reasonably simple requiring only a few key parameters (e.g., Morgan, 1986), productivity erosion runoff functions to evaluate conservation techniques (PERFECT), universal soil loss equation (USLE) and revised universal soil loss equation (RUSLE) to predict runoff and soil loss (Morgan, 1974; Morgan, 1986; Renard et al., 1997). Some models, in spite of their strong theoretical base, may not be very suitable in the context of developing country situations such as those in Indonesia since the detailed rainfall, topographic and other input data required to run them are often not available or difficult to collect due to resource constraints.

Soil erosion models can play a critical role in addressing problems associated with land management and conservation, particularly in selecting appropriate conservation measures for a given field or catchment. They can also assist governmental agencies in developing suitable policies and regulations for agricultural

and forestry practices. Two important considerations in selecting an appropriate model for field use are input data availability or whether data can be obtained within the constraints of the field resources available, and the prediction accuracy of the models. Therefore, an evaluation of potentially suitable models that can be used with readily available input data is an important step in using them for practical applications (Renard et al., 1997).

Despite many efforts made to quantify the extent of soil loss in Malaysia, the available information at this stage is inadequate as it was mainly based on results obtained from selected regions. Therefore more detailed and extensive work is required to assess the spatial variability and extent of soil erosion within given region.