Land Use and Land Cover Mapping for Catchment Monitoring and Management with Remote Sensing Methods

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Abstract

Remote sensing techniques are evaluated for their use in land cover and land use mapping. Catchment monitoring and management requires detailed and up to date information about the surface runoff, cover and use. Remote sensing as a data gathering technique can rapidly deliver very detailed studies of the ground surface. Choice of the instrument, platform and analysis technique varies however depending on the size of the catchment, number and complexity of parameters required, budget and availability of the trained staff to undertake data analysis.

Introduction

Growing populations and increasing urbanisation are changing land cover and land use worldwide. Agricultural land use is replacing natural habitats while the density of houses, roads and other urban infrastructures is growing daily. As a result of these changes, land surface parameters are being altered. Most natural habitats have low rainfall/runoff rates and little nutrient loading, whereas agricultural and urban areas have high runoff, which often carries large pollutant loads. The study of changes to land cover and land use provide useful options on management of our environment. There are many ways of studying these changes and remote sensing provides the most powerful tool to do so.

Remote sensing is the science and technology of gathering data from a distance. Using a variety of sensors, from photographic to electronic, remote sensing can provide data for hydrologic models, runoff management and catchment monitoring. Information which can be obtained includes: land use, land cover or differentiation between permeable and impermeable surfaces, and it is possible to sample the variable of interest many times over large areas. Data sets can be integrated into a system such as a Geographic Information System (GIS) or a hydrologic catchment model.

This paper summarises the manual and digital methods used to map and characterise land cover and land use features. Each method is discussed with an example of the type of the data set to which it is most frequently applied. Examples of methods of visual interpretation are also included.

Remote sensing and GIS have evolved from older disciplines such as photogrammetry, surveying, mapping and photointerpretation. Compared with 30 years ago, modern mapping sciences now incorporate computerised data acquisition, analysis, presentation and data storage. Computer databases offer an unprecedented opportunity to view and integrate a vast number of images and attribute data about the environment. A typical GIS application program is described by Robinette (1991) through examples of land management applications. These include water resources assessment, finding input parameters for a non- point source pollution model and prediction of areas susceptible to groundwater pollution (Robinette, 1991).

Remote sensing in hydrologic studies can be applied to planning scientific or engineering projects, site determination, management and implementation of best management practices. It can be used for water quality measurements, mapping erosion and delineating water bodies. Catchment information such as land cover or non- point sources of pollutants can also be determined.

Prior to obtaining information about land use and cover we need to define the parameters of perceived environmental problem. This is done by defining the magnitude and complexity of the given situation, as well as the rate of change of the variables being studied. In other words we have to define the scale of mapping and degree of detail to be mapped and identify the parameters and frequency of sampling required.

Catchment Information

Accurate, current information about land use and cover is critical in catchment monitoring and management. Aerial photography, airborne digital video recording and, in particular, satellite remote sensing are the most important methods used.

In hydrologic studies, the catchment approach is used in the control of stormwater and in particular of non- point sources of pollutants. Knowledge of functional relationships and their spatial arrangement between land uses and receiving waters helps to design programs for stormwater control. Catchment information is presented on land cover and land use maps; used for planning and management within a catchment. A land cover map describes the surfaces and land use maps tells us how the land is used: for example, the land cover may be vegetation, and the land use may be a golf course, regional park, market garden or nature reserve.

Land cover and land use maps can be used to differentiate between permeable and impermeable surfaces within the catchment which enable calculation of total runoff from the area during storm events. They can also be used to estimate pollutant loadings carried by the runoff to receiving waters.

Compared to the traditional approach, remote sensing methods have a number of advantages:

- images of large areas can be obtained rapidly. For example, an area of 185 km by 185 km is mapped in several months or years by ground based methods such as surveying, in several hours by an aircraft and in just 29 seconds by satellite.
- remote sensing images eliminate the problem of surface access that can make ground surveys difficult. It should be noted though that field visits are always necessary to verify results.
- image interpretation is faster, cheaper and usually more accurate than ground surveys.
- quantitative methods can be applied in image analysis, and therefore an unbiased, baseline data set can be established for a variety of different applications.

Remote sensing is not appropriate for the survey of small areas or where certain types of land use may be indistinguishable on images. Other disadvantages include the high costs associated with obtaining data and the high levels of technology and training necessary for data interpretation (Sabins, 1986).

Remote sensing images can be analysed using either a quantitative or qualitative method. Aerial photographs are generally interpreted visually (qualitative method), whereas most digital data sets (airborne video and multispectral scanner data) are analysed using computers (quantitative method). These methods are not necessarily mutually exclusive. Hybrid methods and more advanced methods based on the neural network approach are becoming widely used in image analysis for land use and land cover mapping (e.g.: Richards, 1993; Barnsley and Barr, 1996).

With data in digital format, radiative properties of the scene are represented by discrete brightness levels which can be translated into colours allowing the image to be interpreted by visual inspection. Alternatively a computer can examine each picture element (pixel) individually and assign land cover class based on statistical probabilities using the characteristics of reflectance of that pixel. Results of any classification have to be checked against ground information.

Traditionally, qualitative analysis relied on instruments such as sketchmaster, stereoscope and series of map overlays. Modern quantitative methods now use mostly sophisticated computer software. Both types of investigation can be presented, for example, as sets of overlays, reports explaining the process of interpretation, detailed interpretation keys, digital maps or scanned photos with digitised overlays.

Mapping Land Use and Land Cover using Air Photographs

a) Techniques

Aerial photography is very well suited to land use and land cover mapping, as it provides a bird's eye view of the ground and can also be georeferenced to a base map. Photographic images are readily understood by most people and like maps, provide a plan view of the area. However, aerial photos are limited in spatial accuracy. They suffer from geometric distortions, particularly near the edges, or with variations in terrain height. Analogue or digital methods, called image rectification, can remove these distortions.

A series of photographs assembled in a seamless fashion is called an aerial photo mosaic. Photo mosaics can be "controlled" or map-like in their positional accuracy, or "uncontrolled" depending on the degree of distortion being removed. Photo mosaics are useful for covering a large ground area and can be printed in the background or beside a land cover or land use map. Mapping projects normally require "vertical" photography, where the camera axis is perpendicular to the ground: an error of 3° tilt either way is permissible. The scale of aerial photography depends on the flying height, variations in terrain elevation and the focal length of the camera.

b) User requirements

Aerial photography provides a three-dimensional, permanent, overall view of the ground at almost any scale desired by the user. Some projects in land cover mapping have special requirements. These may range from different seasons (for example, crop marks show well in the early spring), low sun angle (shadows can considerably aid interpretation), large or small scale, black and white or colour photography. This choice is not always available to the investigator, who is often forced to work with what is available. For example, aerial photography worldwide, except that taken for special local projects, is obtained for topographic mapping purposes, with the specifications made up by the local mapping agency. These photographs typically use scales from 1: 10 000 to 1: 40 000. Standard photography is normally taken as close to midday as possible, to minimise shadows. However, in land use and land cover mapping, shadows can be useful for the detection of the presence or identity of some geomorphic features.

Image analysis projects usually include the following steps: planning, image acquisition, interpretation and analysis, map generation, ground truth sampling, accuracy assessment and final reporting. Data interpretation can utilize both qualitative and quantitative methods.

c) The visual interpretation process

This consists of two stages. Initially, image elements, such as tone, shape, colour and texture are interpreted and translated into land cover classes such as vegetation, rocks or soil types. The second stage involves interpretation of these outcomes in the context of the project aims. For example, identifying land cover and land uses which potentially contribute to water runoff or pollutant runoff, may require additional data sources such as population density, identification of subcategories of some potentially polluting land uses, planning approval documents or other auxiliary data. It is essential that the final maps be verified in the field where possible.

The analyst interpreting the data must take into account several factors. They may be interrelated, for example, high erosion rate may correspond to little soil and vegetation cover resulting from specific climatic or microclimatic conditions (Allum, 1985). The appearance of land cover in an image depends on: climate and season, soil and vegetation cover, absolute and relative rate of erosion, colour and reflectivity of different surfaces, mineral composition of the surface, and general physical characteristics. Other factors inherent to the type of photographic material and the conditions under which the material was obtained, such as normal colour or infrared images or thermal day and night images must also be considered. Identification of some vegetation types, such as perennial and annual types can be aided using multitemporal data.

The procedures of detection, recognition, identification, classification and deduction are integral to each stage of visual image interpretation, and it should be noted that data or information at any of the interpretation stages can be updated whenever new data become available. Thus, a field visit might confirm some aspect of the interpretation or force the interpreter to refine the land cover categories.

Each of these procedures, especially detection and identification, can be accelerated using photo interpretation keys. A key may be useful as training or reference material but, more importantly, should form an integral part of the documentation of any project. Interpretation keys help to systematically arrange and evaluate the information presented on aerial photographs or other remote sensing images, and can be used as guides for the correct identification of features, or their condition. Having a key can also ensure a consistent approach, especially if the project is long term and more than one interpreter is involved.

Typically, an interpretation key consists of two parts: a collection of image samples, possibly as stereograms or sketches, which illustrate features to be identified and a description (pictorial and/ or text), which outlines the image recognition characteristics of objects of interest, or their condition. It should include a list of limitations such as the season or specific location for which they were compiled.

Differing presentations of a particular image element could occur. For example, sites of the same pattern and texture occur in different shapes and sizes such as paddocks with the same vegetation cover. The association or location may indicate that an area apparently covered by grass is a playing field, if located in the suburbs, but a turf farm, if located in the country.

There are two types of image interpretation keys: elimination and selective keys, which differ in the presentation of diagnostic features. An elimination key requires an interpreter to follow a step-by-step procedure leading to the elimination of all features or conditions except the one being identified. Elimination keys are often in the form of a dichotomous flow diagram, where the interpreter makes a series of choices between two alternatives and progressively eliminates all but one possibility. This approach can be very successful but errors often occur when the interpreter is forced to make an uncertain choice between two unfamiliar image characteristics (Lillesand and Kiefer, 1994). A selective key resembles a catalogue of image samples with an explanatory text. The interpreter chooses the example that most closely resembles the feature being interpreted.

The nature of the landscape often determines the procedure of image interpretation and some landscapes may require a specific approach. The occurrence of land types and drainage ways are basic considerations of their presence or absence may indicate a necessity for further research.

d) Image classification

The process of image classification involves the assignment of all pixels in an image to an information class. If no prior knowledge exists on identity and separation between the information classes, we can perform data clustering followed by an unsupervised classification. The analyst then identifies those classes a posteriori using available reference data and field visits. If, on the other hand, we have prior knowledge of the class identity, we would carry out a supervised classification technique.

The supervised classification consists of four main steps:

- Choosing training areas (sample areas) or image portions representative of particular ground cover type or conditions.
- Calculating statistics for each training area.
- Calculating the information class membership for each pixel in the image. There are several possible approaches here (refer to Richards (1993) for further details).
- Accuracy assessment.

The resulting classified image consists of polygons of labelled information classes.

The Digital Airborne Camera and Digital Multispectral Video

Although aerial photography is a reliable, well established technique for gathering data on the earth's surface, there is increasing pressure from data users for digital data formats. It is possible to scan or digitise hard copy aerial photographs or photographic film, but this takes time and introduces geometric and radiometric distortions, which later need correcting. These problems may be solved through the use of digital cameras. These cameras also provide real- time availability and a generally better signal-to-noise ratio, especially in low illumination. Digital photographic systems have been developed over the last two decades, and with improved technology and lower costs, their use has increased. A review of technical issues comparing photographic and electronic imaging is presented by Light (1996).

Digital multispectral video (DMSV) is an example of a relatively cheap and rapid data acquisition system, at a spectral and spatial resolution compatible with aerial photography. This video system consists of four aligned digital cameras. The spatial resolution varies with the flying height and focal length of the lens and can be as small as 30cm on the ground. The four cameras are sensitive in the visible to near infrared region (approx. 425-795nm).

Digital cameras and airborne video systems have advantages over aerial photography, by their extended spectral range, and producing data in digital format. Flying costs are similar and if the project requires a digital product, these systems should be considered. With data in digital format, any number of image enhancements and reproductions can be made without altering the original data. Multivariate statistics can be applied to the data and images classified according to the needs of the project. As with aerial photography, the same data set can often be used for different projects.

Satellite Remote Sensing

Satellite sensors have poorer ground resolution compared with aircraft systems but provide better spectral and temporal resolution. For large areas the cost of satellite data is much lower than for aircraft data. Satellite sensors are fixed in orbit for a number of years, providing extended archival data. Satellites currently in orbit have a variety of sensors measuring ground characteristics in a number of spectral bands. The spectral sensitivity of these systems extends from the visible to the microwave region.

Some of the satellite sensors worth considering for mapping land features are: Landsat TM, SPOT, ERS - 1, JERS- 1 and RADARSAT. Richards (1993) discusses the characteristics of Landsat TM and SPOT satellites and principal applications are summarised by Lillesand and Kiefer (1994). The French SPOT satellite has the unique capability of providing stereo coverage. This enables the interpreter to generate three-dimensional models of the terrain. The Landsat TM returns to the same scene on the ground every 16 days and SPOT every 26 days. A limitation of their use is that they cannot image the ground through clouds.

Radar satellites

Radar sensors have a significant advantage over passive sensors in using visible and infrared bands. Since radar wavelengths are much greater than rain or cloud droplets, radar can "see" through even the most dense cloud cover. In tropical regions, this is the only reliable satellite remote sensing method suitable for gathering data about ground conditions.

Although it is possible to digitally merge data of different spatial resolution and origin, the final accuracy is only as good as the coarsest data set. Examples of ground resolutions and suggested maximum scales of cartographic products are summarised in Table 1.

Table 1. Examples of remote sensing sensors, their ground resolution and suggested maximum scale of cartographic product (Richards, 1993, modified).

Scale	Approximate ground resolution (m)	Sensor
1: 10 000	1	photographic camera
1: 20 000	2	airborne digital video
1:100 000	10	SPOT panchromatic
1: 250 000	25	SPOT HRV, Landsat TM
1: 500 000	50	Landsat MSS

Satellite systems, although of lower ground resolution than aerial photography, may be worth considering for land use mapping, for the following reasons:

- satellite images are already in a digital format
- multivariate statistics may be applied during the analysis
- large number of spectral channels are available on most satellite systems (for example Landsat TM)
- geometric and radiometric errors may be removed from the data
- full spatial and spectral resolution of the data can be used
- seasonal or multitemporal images may provide more information than aerial photography
- data processing can be automated
- cost of mapping per km2 is lower compared to a new air photo acquisition program
- images can be enhanced in many different ways without altering or degrading the original data
- accuracy assessment can incorporate satellite images alone or also with scanned aerial photography
- two adjacent SPOT images can be used to generate a 3-D model of the terrain and used to map the area at 1:50,000 with 20m contour intervals.
- soil characteristics may be studied much more successfully with radar or infra red sensors than with aerial photography.

Comparison of Aerial Photography and Digital Data Acquisition Systems and Methods for Interpretation

Data acquisition

Aerial photography is a mature technology and the technology of data acquisition, film processing and image interpretation has an established reliability. High quality aerial camera systems are widely available and photographic film has a very high spatial resolution. Most countries have good calibration and logistical support systems and aerial photography, (like digital systems) is GPS (Global Positioning Systems) compatible.

Processing of photographic film takes time, clean water and chemicals and the product is not immediately suitable for digital manipulation. Processed film must be scanned before computer processing. Unlike digital data, each generation of photographic products is degraded, and image enhancements are time consuming and unpredictable.

Digital systems have the advantage of real time availability. They have low light level sensitivity due to ease of digital contrast enhancement. The recording medium (computer storage device) is reusable. During flight, images are displayed on the cockpit monitor to confirm acquisition. Once collected, digital images can easily be linked by georeferencing. Images can be transferred electronically and encrypted if required (Light, 1996). New digital imaging instruments, computer processors and data compression routines are still emerging technologies and are not foolproof. Very high data rates are required for the digital camera or video system to be compatible with photographic film resolution. Because digital systems are relatively new, standards do not exist yet for data compression or transmission.

Interpretation

On hard copy images, the range of grey or colour levels is narrow, compared to the usual 256 brightness levels in 8 bit digital data. Consequently, it is difficult to visually discriminate and interpret grey tones. Quantitative techniques are limited, due to the nature of the method. Image registration of photographs or overlays to a map is time consuming and cannot be automated. Digital image analysis has higher equipment costs and requires specialist training as the interpretation process is not necessarily intuitive. Digital data may be expensive for small areas and for a solitary interpretation. Pre-processing may be required, such as radiometric and geometric corrections. On the other hand, digital data analysis is cost-effective for large geographic areas and for repetitive interpretations.

The digital approach gives consistent results, regardless of the number of analysts involved in the project. Simultaneous interpretation of several channels of data is possible and complex interpretation algorithms can be applied. By its nature, the quantitative approach is conducive to exploring alternatives in interpretation and processing. The speed of processing may be an advantage and it is easy to integrate digital data with other numerical data. If aerial photographs have been scanned, a digital, georeferenced mosaic can be compiled without damaging the original photographs. A summary comparison between aerial photography and a satellite system for mapping land cover is presented in Table 2.

Table 2. Comparison between aerial photography and satellite systems.

Parameter	**Aerial photography**	**Satellite systems**
scale	1: 1000 - 1: 80 000	1: 25 000 - 1: 1 000 000
coverage	limited areas depending on demand	global continuous coverage for most systems
spatial resolution	varies with flying height & camera system ~ 0.3 m	1.1 km - 10 m
sensor	choice depending on the aims of the survey	no flexibility
cost	fixed running costs	very high capital costs, relatively low running costs

Depending on the project requirements and size of the study area, digital methods may be preferred. An example, comparing satellite, aerial photography and digital video data is presented in Table 3, based on a riparian vegetation study of an area of 45 by 25 km.

The advantages of remote sensing over ground mapping of riparian vegetation are: total cost is lower, shorter time to complete, favourable viewing perspective, a permanent graphic, digital record compatible with other digital data bases and visual interpretation tends to be subjective, even with the use of photointerpretation keys. In this study by McComb et al . (1995) of saltmarshes of Peel-Harvey system, in the south west of Western Australia, the visual interpretation of aerial photographs of the area of 45 km by 25 km took 14 days to complete, compared with 3 days of processing on a computer.

A brief note on seasonal satellite and air photo images

Studies using Landsat images have demonstrated that images acquired in different seasons may enhance geologic and especially soil features (Lo, Scarpace and Lillesand, 1986).Arid areas during dry seasons are likely to be covered with dry grass and indigenous vegetation that may be leafless or yellow. There may be few tonal variations in the image to facilitate recognition. However, the wet season may enhance vegetation responses to water. These responses will depend on the soil compaction. There may be much stronger tonal variations in ground covers, very likely due to the topography and rocky features of geomorphological significance. This observation applies equally to satellite, airborne scanners as well as aerial photography data. The best results would be seen on imagery incorporating near infrared region, where crop marks are best contrasted from soil due to chlorophyll response. Certain seasonal land covers are best mapped using temporal images. For example, the distinction between perennial and annual vegetation is best made using spring and winter images.

Factors influencing spectral estimates of vegetation

The most common environmental factors influencing target radiance are primarily the quantity and orientation of dead biomass, followed by the amount of soil reflectance in comparison with vegetation reflectance. Factors influencing spectral estimates of soils are: colour, moisture content, mineral content, particle size, and organic matter content. As the moisture of soil increases, regardless of the soil type, the radiance of soils decreases. The same rule applies to organic matter content. Particle size determines the surface roughness and also affects the colour of the surface: the smaller the particles, the lighter the colour.

Table 3. Comparison of satellite, aerial photography and aircraft DMSV instrument for mapping vegetation status for Peel-Harvey system.

parameter	satellite	Hard copy aerial photography	DMSV instrument
ground resolution	fixed, currently the best is around 20m on a system comparable to DMSV (SPOT Multispectral)	variable, depending on scale, standard 1:20000 photography has a resolution of approx. 0.5m	variable, depending on the flying height, as low as 0.5m. The better the ground resolution, the more data to process
spectral resolution	fixed, current satellites have between 4 to 7 spectral bands ranging from 0.4 µm to 12.5µm	from 0.4µm to 0.7µm, can be extended to 0.8µm using infrared film	from 0.4 to 0.8 µm
temporal resolution	fixed, return time to same site about 16 days, time of day always the same	can fly anytime, standard road directory photography is only flown once a year, in summer and it does not include the entire study area	can fly anytime
cost of data acquisition per 1km^2	between \$0.16- 0.80 depending on the sensor and amount of data required	approx. \$1.8* for colour photography, depending on the number of photographs, their scale and shape of the area (number of runs)	approx. \$25.00**, depending on ground resolution, size of the area and location
radiometric corrections	desirable	any of these correction are only relevant if the photography is to be scanned	desirable
geometric corrections	provided by the supplier		desirable
atmospheric corrections	desirable		desirable
hot spot corrections	not relevant		desirable
histogram matching	not relevant, unless more than one image used		desirable
geo-referencing	desirable	not relevant	desirable, very time consuming
mosaicking	usually unnecessary, because single image covers between 60x60 km to 180x180km on the ground	unnecessary if only used for photointerpretation and map compilation	essential and very time consuming

* cost estimate assumes minimum overlap between the photographs.

** cost of acquiring data of current study was used to calculate this figure.

Compilation of Land Use and Land Cover Maps

'Once only' or multi temporal land cover databases can be compiled using a number of image processing techniques, or be manually drawn on base maps. Visual image interpretation sheets are usually compiled manually. Boundaries of land use covers can also be traced on a computer screen and saved as polygons with associated attributes. Automated, spectral classification can be applied to digital airborne video data or satellite data. Usually, a GIS is used to assemble and integrate the data.

Historical aerial photographs can be particularly useful as they record a variety of conditions and changes of land cover. When using historical sources (maps, sketches, aerial photographs), land cover classes can be compiled by visual interpretation and delineation on mylar overlays. The interpretation is based on map or photo features such as tone, shape, street density or building location and key for image interpretation is compiled. After the mylar overlays are annotated, they can be either digitised to the computer data base, or overlayed on the base map. Depending on the scale and projection differences, some geometric corrections may be required.

Using GIS, a single coverage is generated for each theme such as water or urban/commercial. When using solely contemporary data sources, land cover and land use maps can be prepared entirely on a computer. Satellite data or airborne video data are most suitable for mapping large catchments. Initially, unsupervised image interpretation can be carried out and if additional digital maps such as road network or other themes exist, they can be entered into the computer at this stage.

Accuracy Assessment

Accuracy assessment is an important final stage of any interpretation process, whether machine or computer assisted. This allows a degree of confidence to be attached to the results and indicates whether the interpretation objectives have been achieved. Reference data as well as field checks are necessary for this assessment, and accuracy is determined empirically by comparisons to the reference data. A number of locations should be chosen on the final map and their identity compared to the reference data. From the identity of those chosen pixels a matrix, can be compiled. The matrix is known as confusion or error matrix, which lists the omission and commission errors.

Conclusion

A number of different instruments, based on photographic and electronic method of data collection have been successfully used for land cover and land use mapping. Parameters such as permeability of the surface, type of vegetation, soil can be derived form remote sensing and used in GIS and hydrologic catchment models. Cost of data acquisition, sensor resolution, complexity of the analysis and interpretation of data should be considered when selecting a mapping method for a particular application.

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