USE OF RADIOMETRICS IN SOIL SURVEY

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Abstract

The objectives and requirements with soil mapping are summarised. The capacities for different methods to address these objectives and requirements are compared. Basic requirements when analysing radiometric data for soil mapping are given

Introduction

Airborne measurements of gamma radiation (radiometrics) have been available for more than 30 years and so are not new. However, developments associated with computers, particularly techniques for numerically processing and displaying raster imagery, have allowed production of results not previously possible. Together with improvements in the quality and availability of radiometric data this has made practical the use of these data in mapping soils. This availability of a ‘new’ form of information useful for mapping soils creates a need to examine the reasons for mapping soils, and the means of application.

Objectives with Soil Mapping

The reasons for soil mapping generally have not changed. The prime reason for a small group of researchers is to improve understanding of pedalogic processes, but it is utilitarian for most. Funding for soil mapping is provided to address community requirements for information to support land use.

While the general reasons for mapping soils have not changed the expectations of the users and beneficiaries have. Regional development was the main concern of those initially funding soil mapping where planning decisions could be based on coarse or generalised information. The probabilistic distribution of broad soil types within large polygons provided adequate information. This continues to be the priority with government expenditures as the responsibility of agencies is identified as stopping at the farm gate.

The focus is now on the sustainability land use where this can only be achieved through management outcomes. Management decisions depend on site-specific information hence the need is now for accurately located, purpose specific information on the main environmental variables such as soil, vegetation, and terrain. The need is also for information directly applicable to management, such as soil pH, texture and salinity, rather than soil types defined by way of a prior classification.

This need for detailed soils information creates an associated need for an efficient means of application. Application has previously been addressed by employing experts to interpret the available information and to make new observations. This approach is expensive and, given the limited number of personnel with the necessary expertise, highly limited in its capacity to address community needs. Also, the subjectivity of methods seldom allows evaluation of cost benefit and this blocks investment from those can benefit from improved soils information.

Nature of the Required Soil Information

The trend has been towards direct delivery to the user of information specific to their requirement. For soils this entails providing information on soil properties relevant to applications at appropriate levels of precision and reliability. Descriptions of soil type generally have limited direct applicability, regardless of the classification system used, because of the need to infer the properties of interest from soil type. Similarly, probabilistic information on soil distribution, as given by the occurrence of soil types within soil landscapes, has limited value because the high uncertainty associated with location.

Identifying soil types facilitates communication amongst those familiar with the classification, but it is also usually inferred that its use improves understanding of pedologic processes. While this communication role is important, particularly in the initial stages of a soils education, logic indicates that strict adherence to any classification ultimately restricts the development of understanding except where the classification is functionally based and absolutely correct.

The periodic table provides an example of a functionally based classification where allocation to a class is unambiguous. The approach used for 'functionally based' soil classifications derives from plant species where genetic constraints create phyllogenetic associations. No such classification can exist for soils because of the absence of any necessary association, thus the fitting of new observations to an existing soil classification will restrict analysis and interpretation. Use of soil types defined by way of a prior classification restricts the development of understanding as well as practical application.

Site specific information on soil properties represents the ultimate requirement but the properties of interest will vary with location and application. No single soil map will meet all requirements. Efficient delivery of information therefore requires an ability to make maximum use of existing information and a minimal need to obtain new observations. Soil landscape maps have been constructed for this purpose but application has been limited by the lack of spatial specificity and uncertainty as to relationships between soil properties and types. The lack of spatial specificity arises because soils are located by way of position in the landscape (catenary position) when this is not mapped and when a number of different soil types can occur in a catenary position.

Accepting that no single map will meet all applications the requirement is for site-specific information on soil properties of most interest mapped at a defined spatial resolution across an entire area. However, application also requires that the mapped information be derived independently of other information used in application. Also, an indication should be given as to the reliability of discrimination of properties and the spatial resolution.

The question of reliability has traditionally been addressed through the specification of standard techniques rather than estimating error. This partly arises because of difficulties in evaluating accuracy where information is given by way of mixtures of categories within polygons. However, the assumption that application of standard techniques produces uniformity of results has little validity because of gross differences between systems throughout Australia and the subjectivity inherent in the soil landscape mapping methodology.

Numerical analysis of radiometrics and explicit mapping of soil properties allows statistical evaluation of results. The key issue relates to obtaining the funds needed for such an analysis as consumers do not see benefit in such expenditures.

Information Delivery

The means used to deliver information have strongly influenced the results provided from soil survey. This still applies but the constraints have changed. Computer based Geographic Information Systems (GIS) are replacing paper maps but this transition is still in an early phase with GIS mainly being used as a direct replacement for paper maps. Spatial location is still coarse, being defined by way of mixtures within polygons. Most importantly, however, the mapped distributions are still being determined by reference to any information thought useful where much of this information, such as terrain, would normally be used in subsequent analyses associated with applications.

Paper maps generally contain all the information considered relevant to the application and can comprise multiple sources of information. With GIS the base information layers should represent discrete variables that have been derived independently to allow for reliable analysis. For example, soil boundaries should be mapped independently of terrain where the relationships between soils and terrain are to be investigated or where both soil and terrain are to be used in the evaluation of land capability / suitability. This requirement for independent derivation of the base map layers in GIS means that very few of the existing soil maps are suitable for application using GIS. No soil landscape map is suitable for analysis with vegetation or terrain information.

The focus on defining soil distributions by way of lines or polygons (vectors) reflects technological constraints associated with visual analysis of aerial photography. With numerical analysis of raster imagery these constraints no longer apply and the new technology is more efficient, effective and objective than visual analysis. Use of a raster allows presentation and comprehension at higher spatial resolution that possible with vectors and facilitates analysis through the spatial information being embedded in the data structure. Raster data can be converted to vector but with considerable processing and degradation of the information, and hence is generally only undertaken where visual examination of association is desired.

Requirements with Soil mapping

The prime requirement is for a reference or base GIS layer that reflects patterns of soil properties where:

- The base layer is derived independently of other variables that will be used in subsequent analysis and application
- The relationships between the reference (mapped) layer and soil properties of interest are established along with estimates of error.
- The information is presented as a raster of known resolution and accuracy
- The methodology used in the derivation of the base layer is objective and generic.
- The base layer can be produced cost efficiently
- The information needed to meet new applications can be cost effectively mapped by reference to the base layer and associated database information.

An evaluation of the extent to which these requirements are met by different methods is given below.

Uncertainties exist with these assessments because of differences between applications and areas. Landscape analysis, for example, can be conducted in analytical or predictive modes, and for soil types or soil properties. Also, costs of application depend on the availability of data. The cost of aerial photography and elevation data is seldom considered whereas the cost of radiometrics typically has been.

While the assessments below are partially subjective the main differences between perceptions will relate to the attributes considered significant rather than the ratings. Those not involved in numerical analysis, and apparently some that are, will not consider independence in the derivation of GIS layers to be of consequence when it is fundamental to subsequent application of the results.

The main dichotomy in perceptions relates to whether the soil map is perceived as the final product or whether the soil mapping is provided as a service to support land use and management. The pedologic view appears to be that the objective is the production of a map of soil types and the development of understanding. Application is assumed to be an automatic extension when the use of soil pedalogic soil types can hinder the development of understanding as well as limiting application of the results. The suggested alternative is to produce results that directly map the distribution of soil properties throughout the landscape which can only assist in developing understanding.

	Air Photo Interpretation	**Satellite Imagery Interpretation**	**Landscape analysis**	**Landscape analysis with radiometrics**	**Numerical analysis of radiometrics**
Analysis	Visual	Combined numerical, visual			Numerical
Soil Properties	No	No	Yes / No	Yes / No	Yes
Independent Derivation	No	No	No	No	Yes
Determine Associations	No	No	Yes (usually by definition)	Yes (usually by definition)	Yes (by analysis)
Error with associations	No	No	Possible but difficult	Possible but difficult	Yes
Estimate of spatial error	No	No	No	No	Yes
Objectivity of methodology	Low	Low	Moderate to High	Moderate to High	High
Generic method	Location dependent	Location dependant	Location dependant	Location dependant	Data dependant
Cost effectiveness	Only for small areas	Moderate for large areas	Low	Low	High, particularly where data exist
Cost effective extension	No	No	No	No	Yes

Field Truthing

Estimates of costs differ markedly depending on whether they are based on marginal costs, as typically done by publicly funded agencies, or full commercial rates, where the latter identifies the true cost of mapping. However, the main difference in costs invariably derives from differences in the amount of field work required to produce a useful result. The figure often given for field truthing a 1:100,000 soil landscape map is between 1,000 and 2,000 sites although the basis for these figures is not evident. A soil map derived from radiometrics can usually be reliably labeled using 150 accurately located sites provided the radiometrics are appropriately analysed and the field observations correctly structured.

The difference between the field sampling requirements for different methods relates to the degree to which the base maps identify the distribution of soils. The radiometrics reflect patterns of soil properties hence few samples are required. Patterns in soil landscape maps represent a subjective interpretation of expected patterns. Where this interpretation does not reasonably reflect soil patterns no amount of field sampling will produce a good result.

Numerical Analysis of Radiometric Data

This section addresses basic concepts to applying any remotely sensed imagery in natural resource mapping rather than issues particular to radiometrics. Visual analysis is not addressed because it is subjective and fails to take advantage of the detailed information in the radiometric data. Moreover, visual analysis is usually combined with a soil landscape analysis hence the result is not suitable for subsequent analysis with information such as vegetation and terrain.

The basic requirements are that the imagery must contain information on the variable of interest and that this information can be discriminated against a background of irrelevant information and noise. Discrimination is normally achieved by reference to spectral signatures hence the basic assumption is that similar features have similar spectral characteristics. However, spatial context by way of association or shape can also be considered invoking assumptions that similar features either are spatially associated or have similar shapes.

The identification of features from spectral signatures alone seldom provides unambiguous results because the spectral signatures of equivalent features can vary across the area of interest, dissimilar features can have equivalent spectral characteristics, and the measured signal can represent a composite or mixture of features. The first situation is common with vegetation analysis using satellite imagery but radiometric signals for features are usually consistent across a survey.

While native vegetation always represents a mixture of the entities (species / plants) many pixels in radiometric images invariably represent mixels because of the spatial characteristics of the measurement. Mixed pixels (mixels) in radiometrics are most readily identified along the boundaries between major features but they occur along boundaries between all classes. This must be taken into account with field sampling by obtaining field samples from within homogeneous areas. This, and the requirement for measurements of soil properties, limits the ability to use existing field soil information.

The extent to which mixels affect the result depends on the answer required and the resolution of the radiometric data. That is, evaluation requires prior knowledge of the outcome when a study is usually undertaken because the outcome is unknown. The uncertainties as to the correct answer, which are usually pronounced for soils, are of particular consequence in the evaluation of reliability. There is no reliable reference for evaluating the quality of a result or for comparing results from different methods.

Ambiguities arising from different features having equivalent spectral signals are common in satellite imagery but are usually readily resolved through some form of regionalisation. Such ambiguities are also common with radiometrics, partly because of the limited spectral resolution, but mainly because two factors have a pronounced effect on the measured signal. The same signal can arise for different reasons. Removal of these ambiguities depends on the identification of parent material to separate these affects from those due to alteration through weathering and transport.