A comparison of land unit delineation techniques for land evaluation in the Western Cape, South Africa

Adriaan van Niekerk*

Department of Geography and Environmental Studies, Stellenbosch University, South Africa

ABSTRACT

Land evaluation, an integral part of land use planning, has been established as one of the preferred methods to support sustainable land use management. In essence, land evaluation aims to compare and match each potential land use with the properties of individual parcels of land, also called land units. A land unit is an area that is, according to predetermined properties, different from the surrounding land and can be assumed to have homogeneous land properties (e.g. climate, soils, cover). Land components (also called landform elements, terrain units or land surface segments) are often used as land units, mainly because their boundaries frequently coincide with transitions in environmental conditions. Although land components have traditionally been delineated by studying topographical maps, interpreting aerial photographs and making field measurements, such manual mapping techniques are very time-consuming and subjective. Land component maps can be generated more objectively and faster by using computer algorithms. This paper compares the maps produced by three algorithms, namely the automated land component mapper (ALCoM), the iterative self-organizing data analysis technique algorithm (ISODATA) and multi-resolution image segmentation (MRS), to determine which technique produces the most homogenous and morphologically-representative land components for an area in the Western Cape province of South Africa. The results revealed that the three methods produced significantly different land component maps. While ISODATA's units were relatively homogenous, their boundaries rarely followed morphological discontinuities. ALCoM performed better in delineating land components along terrain discontinuities, but produced relatively heterogeneous land components. Overall, MRS performed consistently well and was significantly more sensitive to morphological discontinuities than the other two methods tested. Land use managers should, however, use MRS with care as more research is needed to determine what effect its different input parameters have on land unit boundaries.

KEYWORDS

Land evaluation, Land use, Land component, Land unit, Landscape, Segmentation

* Tel: +27218083101; Email: avn@sun.ac.za; Postal address: Private Bag X1, Matieland 7602, South Africa

Introduction

Land evaluation considers the properties (e.g. climate, soils, cover) of a parcel of land so as to make recommendations about realistic alternatives for improving its use (Németh et al., 2006; FAO, 2007). According to the guidelines issued by the Food and Agriculture Organization of the United Nations (FAO, 1976, 1984, 1985, 2007), land evaluation is an integral part of land use planning and has been established as one of the preferred methods to support sustainable land use management. It gives a holistic, multi-disciplinary approach to sound development and conservation by combining economic and social principles with environmental, agricultural and biological sciences.

In essence, land evaluation compares and matches each potential land use with the properties of individual parcels of land (FAO, 2007). Such land suitability analyses are carried out on predetermined map units, called land units. Land units are areas with properties that differ sufficiently from those of other land units to affect their suitability for different land uses. Although any parcel of land can be considered a land unit, it is more efficient and meaningful to use parcels that can be adequately described in terms of one or a combination of land properties. A land unit should therefore represent an area that is, in terms of predetermined properties, different from the surrounding land and can be assumed to have homogeneous land properties (FAO, 1984). The degree of homogeneity or internal variation will vary depending on the scale and intensity set out in the evaluation objectives (FAO, 1976). When a reconnaissance evaluation is carried out over a large region at a small map scale (i.e. 1:500 000 or smaller), large generalized land units such as climatic zones would be sufficient (Samranpong et al., In Press). For more detailed studies carried out at large map scales (i.e. 1:25 000 or larger), smaller map units such as soil types would be more appropriate (Ziadat, 2007). Landforms are often used as land units in medium-scale studies (1:25 000 to 1:500 000) because many physical land properties, including soil, climate and biology, are related to terrain (Speight, 1977; MacMillan et al., 2004).

Although the size of the land units should be kept as small as possible to limit generalization, too many units can become unmanageable as each individual land unit is considered individually regarding its land properties and requirements. Fortunately, capacities to handle large numbers of land units have increased considerably with the use of computer technology and often the decision about the size, number and delineation of land units is determined by data availability. While soil type boundaries would probably be the most suitable delineation of land units for agricultural land uses, soil information is often not available at the required scales. In such cases other available data sets, such as land components, can be used instead. Land components, or elementary landform units after Minár and Evans (2008), are often used as land units, mainly because their boundaries frequently coincide with transitions in environmental land properties such as soil, climate and biology (Speight, 1977; MacMillan et al., 2004). Land components such as cliffs, valley floors and channels are the most basic subdivisions of landscapes and can be combined to develop more complex geomorphological features such as landforms, hillslopes, land systems and land regions. Land components can be mapped by studying topographical maps, interpreting aerial photographs and making field measurements (Speight, 1977; Graff and Usery, 1993). Such manual techniques rely on the interpreter's implicit terrain-related knowledge of the area being studied (Irvin et al., 1997) and require skills that are the product of long and expensive training and experience (Argialas, 1995). A major drawback of manual terrain analysis is its subjective nature, because in most cases it is impossible to make any useful comparisons between land component maps produced by different analysts or even by the same analyst at different times (Speight, 1977). In addition, the interpretation and mapping of land components are extremely time-consuming, labour-intensive and prohibitively expensive tasks (Adediran et al., 2004).

The increasing availability of digital elevation models (DEM) has promoted the use of computer technology for calculating and discriminating terrain properties. DEM-derived data sets such as slope, aspect, hydrographical pattern and shaded relief are not only less prone to human error but can be used to objectively and quantitatively compare terrain units (Dymond et al., 1995; Giles and Franklin, 1998). A common approach to mapping land components is to use geographical information systems (GIS) to analyse and combine DEM derivatives (e.g. slope gradient, aspect and curvature) to create unique morphological units (Dikau et al., 1991; Adediran et al., 2004). The process of delineating (or segmenting) land components from DEM is a fundamental research problem in geomorphology (Minár and Evans, 2008). One methodology is to identify morphological discontinuities (i.e. slope breaks, slope changes and inflections) by finding local extremes of altitude, slope gradient, and other DEM derivatives. This morphological mapping or graph-based approach assumes that land surfaces consist of planes bounded by morphological discontinuities and that these planes represent individual land components. However, developing computer algorithms to successfully detect and delineate subtle discontinuities is challenging, particularly when relatively low resolution DEM are used as input (Dymond et al., 1995; Van Niekerk and Schloms, 2001). Another approach to land surface segmentation is to define land components according to their internal properties. In this classification approach, map units (cells) that have similar attributes (e.g. slope gradient, aspect, plan and profile curvature) are grouped together to produce classes with minimal "intraclass" and maximum "interclass" differences (Irvin et al., 1997; Romstad, 2001). The classification is then applied to the original input data to produce regions representing similar terrain properties. Although many variations of this approach exist (e.g. overlaying, cluster analysis, fuzzy sets) they all aim to classify terrain into "homogeneous regions". A recent variation of this methodology is the use of object-orientated techniques to segment and classify elementary units. The ability of multi-resolution image segmentation (MRS) to extract locally distinct "objects" from multiple input variables holds much potential for geomorphologic applications (Blaschke and Strobl, 2003; Dragut and Blaschke, 2006).

Although many authors have developed and applied numerous variations of the graph-based and classification approaches to land surface segmentation, none have attempted to objectively compare the results of different methodologies. Consequently, very little guidance is available to land use managers about which segmentation method is superior for land unit generation. This paper applies and evaluates three algorithms, namely the automated land component mapper (ALCoM), the iterative self-organizing data analysis technique algorithm (ISODATA) and MRS to determine which one produces the most surface-representative land components.

Materials and methods

Segmentation algorithms

ALCoM, ISODATA and MRS were chosen for comparison due to their accessibility to land use planners, all three being implemented in popular, "off the shelf" software packages. In particular, ALCoM was selected as it uses a graph-based approach to segmentation, while ISODATA is a popular clustering technique used in classification-based segmentations. ALCoM and ISODATA are both implemented in ESRI software (ESRI, 2009) which are used by more than 75% of GIS professionals (GISjobs.com, 2006). Being the most recent innovation in land surface segmentation, the Definiens Developer (Definiens Imaging, 2007) implementation of MRS was also considered for comparison. The following sections describe each of these algorithms in more detail.

ALCoM

The inability of GIS classification and overlaying techniques to accurately identify and map slope breaks prompted the development of slope break detection algorithms (Dymond et al., 1995). One such algorithm, ALCoM, was developed by Van Niekerk and Schloms (2001) to overcome some of the limitations of the algorithm proposed by Dymond et al. (1995). ALCoM relies on a statistical technique to identify natural breaks in slope-gradient data. The algorithm starts with the creation of an aspect raster, which is then classified into eight 45°-aspect classes. The resulting aspect classification is then regionalized, resulting in unique polygons representing individual aspect regions or directional hillslopes. The focus of the algorithm then changes from a global to the local level by calculating the slope gradient for each aspect region. The most prominent slope break in an aspect region is then determined by employing Jenks' (1967) natural break detection technique with the number of breaks set to one. Next, the variance of each of the resulting land components is determined and the detection of slope breaks is repeated with increasing numbers of breaks until each of the resulting land components is homogeneous regarding slope gradient. To determine homogeneity, the slope gradient variance (SGV) of each land component is compared with the SGV of the entire aspect region. A land component is considered to be homogeneous only if its SGV is lower than a certain percentage (set by the user) of the overall SGV of the aspect region. A lower SGV threshold results in the mapping of smaller, more homogeneous land components, while a higher percentage produces larger, less homogeneous land components. Once the acceptable level of homogeneity is reached, the next aspect region is considered. The algorithm terminates when all land components for all aspect regions have been mapped. Applications of ALCoM have shown that the boundaries of its resulting land components closely match those of soil types (Van Niekerk and Schloms, 2002). However, the technique tends to be very sensitive to prominent slope breaks and less sensitive to subtle terrain discontinuities such as those found at transitions from valley bottoms to pediments (Van Niekerk and Schloms, 2001).

ISODATA

Image clustering's ability to efficiently analyse large data sets to produce areas with homogeneous properties prompted its use for the automated demarcation of land components. One such clustering technique, ISODATA, is frequently used to cluster multiband satellite imagery into regions of similar spectral reflectances (Hall and Khanna, 1977). ISODATA separates all cells of a multiband raster into a specified number of distinct groups in multidimensional space. When assigning a candidate cell to a cluster, the algorithm uses an iterative approach to compute the minimum Euclidean distance between the candidate cell and all cluster centres. The process starts with the specification of the number of classes (clusters) needed, followed by the assignment of arbitrary mean values to each class. Each raster cell is allocated to the closest class mean in the feature space, after which class means are recalculated and each pixel is again allocated to the new class means. This procedure is repeated several times until the class means stabilize (Gibson and Power, 2000). The resulting classes are regarded as unique spectral combinations and, in most cases, are combined and converted to information classes such as land cover (Campbell, 2006).

Instead of using ISODATA on satellite imagery, Adediran et al. (2004) and Irvin et al. (1997) employed the technique on terrain attributes such as elevation, slope gradient, aspect and curvature to map land components. Although the approach produced relatively good results, the histograms of many of the land components had multimodal distributions, indicating that the land components were not homogeneous (Irvin et al., 1997). This is attributed to ISODATA's use of global thresholds instead of local contrasts to create clusters, which often lead to overclustering (i.e. producing units that are too small) and/or underclustering (merging regions that do not belong together).

MRS

Like clustering, MRS groups pixels into spatial regions (segments) which meet predetermined criteria of homogeneity (Baatz and Schäpe, 1999). The main difference between clustering and MRS is the way in which the image is regionalized. While clusters can consist of one or more groupings of pixels that have similar attributes in the context of the entire image, segments are individual pixel groupings that are locally different from adjacent pixels. In other words, the focus is on identifying boundaries between dissimilar areas rather than on identifying groups of pixels of similar characteristics.

Among the various existing image segmentation methods, region-growing segmentation is the most popular. Region-growing segmentation clusters adjacent cells if they have similar attributes. The segmentation process starts with a number of seed points that are randomly sampled, statistically determined or specified by the user (Mancas et al., 2005; Thakur and Anand, 2005). The advantage of using randomly-sampled seed points is that the procedure is autonomous and requires no input from the user. This approach can, however, lead to unpredictable results as the segmentation is highly sensitive to the initial positions of the seed cells. The use of random seeds also means that the process cannot be repeated to produce the same segmentation result. Better segmentation results can be obtained when seed points are statistically determined, but such measures are related to the global feature space (i.e. all pixel values) of the image and are therefore sensitive to outliers. Any change in the extent or position of the image will produce different seed points, which means that the segmentation will yield different results.

Seed points can also be specified by the analyst. Miliaresis (2001), for example, used cells that were pre-classified as ridges to discriminate mountainous and non-mountainous regions from a DEM. In another terrain application, Giles and Franklin (1998) selected seeds based on field surveys and aerial photo interpretation to map land components. Campbell (2006) warns, however, that the use of training data imposes a structure on the clustering which might not match the natural clusters that exist in the data. In addition, the selection of training data can be a time-consuming, expensive and tedious undertaking, especially for large regions.

To overcome the limitations of region-growing image segmentation algorithms, Baatz and Schäpe (1999) developed an algorithm to extract homogeneous image objects based on local contrasts. An important feature of this technique is that segmentation can be repeated to produce the same results, even if the extent or position of the image is changed. The so-called MRS technique can operate on multiple bands (data layers) simultaneously and it can produce multiscale segmentations on images having different resolutions.

The MRS algorithm is based on a pairwise region-merging technique which consecutively merges image cells. It involves an optimization procedure which, for a given number of objects, minimizes the average heterogeneity and maximizes their respective homogeneity. The procedure starts with single seed cells, which are iteratively merged into larger units while the upper threshold of homogeneity is not exceeded locally. If none of the neighbouring cells fall within the allowed thresholds, the best candidate becomes the seed and the merger process is repeated. This approach minimizes variability within merged cells (Baatz and Schäpe, 1999). The homogeneity threshold is indirectly set through a scale parameter which determines the number of segments that will be created. Conversely, variation within each segment increases as the scale parameter increases. Too high values could therefore lead to the loss of important detail, while too low values can result in an unnecessarily large number of small and almost identical segments (Definiens Imaging, 2004).

MRS was employed by Dragut and Blaschke (2006) for delineating landform elements at various scales and resolutions. Input variables used for the segmentation included elevation, profile curvature, plan curvature and slope gradient. The results show that MRS produced “meaningful” segments which proved to be very suitable for geomorphologic mapping. Slope aspect was not included as an input parameter as it introduced an additional zonation which made the output too confusing to interpret. The inclusion of slope aspect was considered to be a priority in further work as it is very important for species-specific geo-botanical mapping and slope stability studies.

Study area

The segmentation algorithm comparison was carried out in a 15km by 5km area (7500 ha) in the Stellenbosch region, South Africa (see Fig. 1). The area, extending from 33°55’02” to 33°57’49”S and from 18°50’06” to 18°59’57”E, was chosen because it includes a variety of terrain types ranging from hills and open valleys in the west to precipitous cliffs in the east (Fig.

2). Elevation ranges from 72 m above sea level in the south-west to 1473 m in the east, with an average elevation of 428 m. The mean monthly temperature range is 11-20 °C with the mean annual temperature being 15°C. The mean annual rainfall is nearly 1000 mm, with a concentration of rainfall during May-September. While the steep slopes (up to 69 °) of the eastern mountains are dominated by sandstones (Table Mountain Group), the western parts of the study area are characterized by moderate gradients and sedimentary deposits, resulting in a mean slope gradient of 15 ° for the entire region. The dominating land use in the area is nature conservation (3810 ha), while other prominent land uses include agriculture (1978 ha), urban (1233 ha) and forestry (794 ha). The agricultural and urban activities are mainly limited to the low-lying areas, while the mountainous areas in the east are primarily used for forestry and nature conservation.

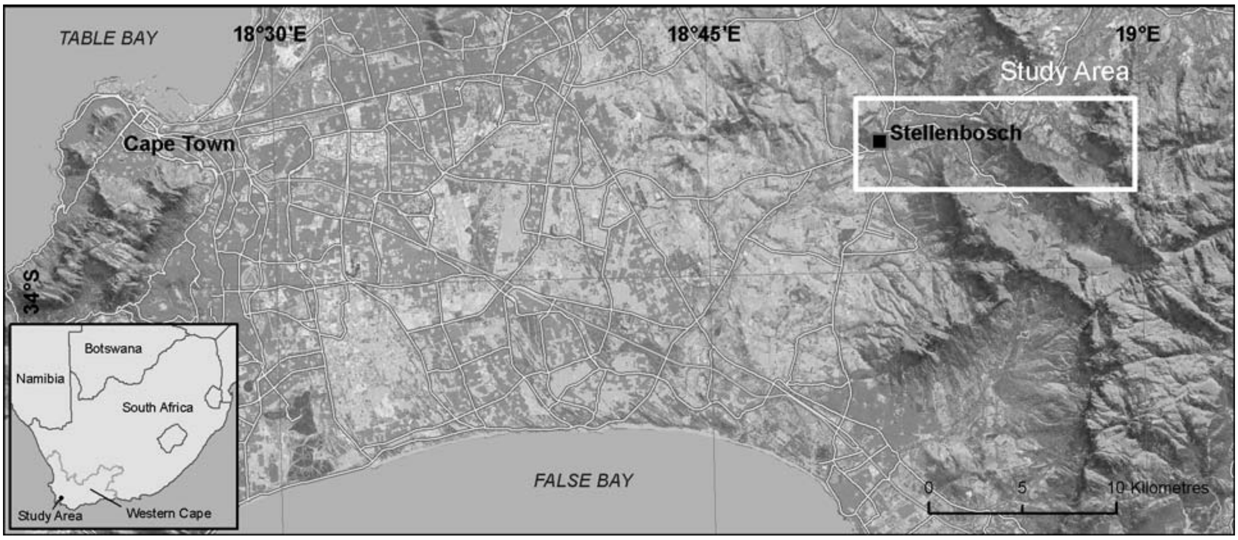

Figure 1 Location of the study area.

Assessment methods

Two assessment methods were used to evaluate and compare the land component maps generated by ALCoM, ISODATA, and MRS. The first assessment addresses each algorithm's ability to delineate land components along morphological discontinuities (i.e. slope gradient and aspect breaks). This was done by comparing the boundaries of the generated land components with terrain discontinuities identified using visual interpretation. To enable a spatial comparison of discontinuities and the generated boundaries, a set of 1000 random locations was created for analysis purposes. Those points that were identified by means of visual interpretation to be located on a discontinuity were overlayed onto the land component maps to determine the level of spatial correspondence. The visual interpretation was carried out on a 1:50 000 topographical map of the study area by two terrain analysts. The resulting points representing discontinuities are shown in Fig 2. Of the 1000 random points, 246 (24.6 %) were considered to be within 50m (i.e. 1 mm on the map) of a discontinuity.

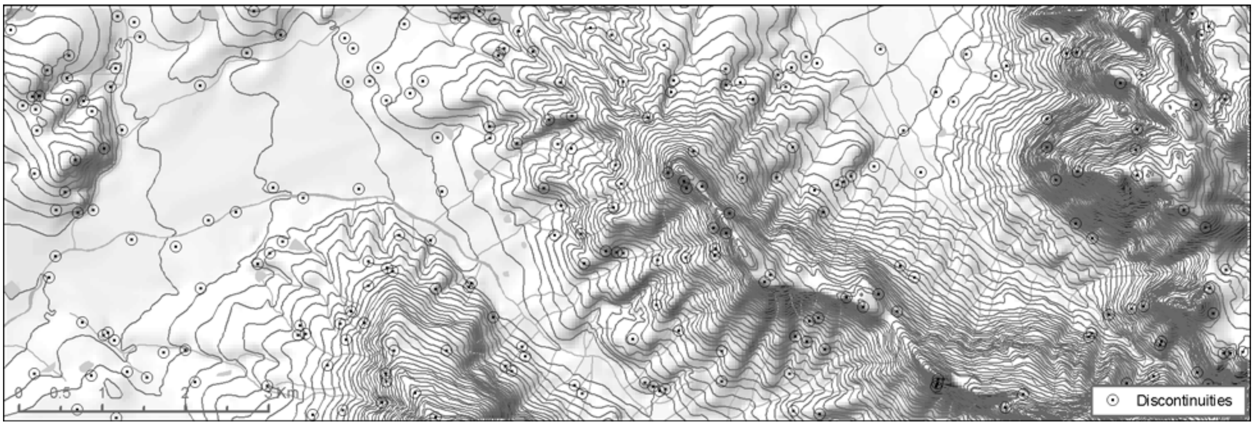

Figure 2 Topographical map of the study area showing 246 points representing morphological discontinuities.

The second method used to assess and compare the three segmentation algorithms involved the use of statistical measures to quantify the internal homogeneity (i.e. intraclass differences) of the generated land components. Internal homogeneity was estimated by examining the variation of the DEM-derived terrain property values (i.e. slope gradient and aspect) of cells located within each land component. Land components were considered to be more homogeneous when the standard deviation of cell values within a particular land component is relatively small. The assumption was that a land component map containing a large proportion of units with relatively small standard deviations would be indicative of an algorithm's ability to produce homogenous segments.

Input data

For comparison purposes, the same DEM was used as input to all three segmentation algorithms. To make the research results more applicable for regional land management in the Western Cape, only DEM that completely covered the province were considered. The first such DEM, namely the Western Cape DEM (WCDEM), was interpolated by the Centre for Geographical Analysis (CGA) at Stellenbosch University from 20 m-interval contours digitized from the 1:50 000 topographical map series of South Africa. The WCDEM was interpolated at a resolution of 40 m using ANUDEM software and was hydrologically corrected by removing sinks. No streams or any other topographical features were incorporated in the interpolation process. The other two DEM that covered the entire province are the 90 m-resolution Shuttle Radar Topography Mission (SRTM) DEM that was produced using C-band radar data (NASA, 2005) and the 30 m-resolution Global Digital Elevation Model (GDEM), generated from stereo-correlated ASTER scenes (NASA, 2009). Both the SRTM and the GDEM were obtained from the United States Geological Survey (USGS, 2009), while the WCDEM was obtained from the CGA.

Although various factors influence DEM quality (Thompson et al., 2001; Hengl, 2006), only vertical accuracy and resolution were considered for selecting an appropriate input DEM. While the resolution of each candidate DEM was already known, the vertical accuracy was not available for all three data sets. Although accuracy assessments have been conducted for SRTM DEM (Rabus et al., 2003; Rodriguez et al., 2005) and GDEM (ASTER GDEM Validation Team, 2009), the results indicated that both these DEM have a high spatial variability in terms of accuracy. To enable better comparison between the available DEM for the task at hand, the mean absolute elevation error was calculated for each DEM using 155 surveyed reference points in the study area. The results showed that the WCDEM has a mean error of 7 m (standard deviation 13m), while the mean errors of the SRTM DEM and GDEM are 17 m (standard deviation 44m) and 15 m (standard deviation 25 m) respectively. who calculated Although the resolution of the WCDEM is 10m lower than that of the GDEM, its significantly higher (8 m) overall vertical accuracy was the determining factor in selecting it for input to the segmentation algorithms. The slope gradient and slope aspect surfaces that were inputted to each of the methods tested were generated using ArcGIS 9.3 software.

Input parameter tuning

Because the number of land components generated by each mapping method is determined by a user-defined input parameter (i.e. slope gradient variance, number of classes and scale factor), it was important to tune these parameters so that the resulting land component maps contained a comparable number of units. The approach taken was to systematically adjust the parameter values of each algorithm until a set of parameters produced a similar number of land components. Table 1 summarizes the sequence of input parameters applied and the corresponding number of units produced for each algorithm. The input set that produced the smallest range of land component numbers (1101, 1003, 1087) was 0.5, 5, and 7. This input parameter set and its corresponding set of land component maps were consequently selected for assessment purposes.

Table 1 Input parameters applied for each algorithm and the number of land components produced.

ALCoM		ISODATA		MRS	
Input parameter (SGV)	Number of land components	Input parameter (classes)	Number of land components	Input parameter (scale parameter)	Number of land components
0.7	690	4	526	9	734
0.6	891	5*	1003	8	906
0.5*	1101	6	1172	7*	1087
0.4	1275	7	1771	6	1395
0.3	1458	8	2325	5	1876

* Input parameter set that produced the smallest range of land component numbers.

Results

The land component maps generated using the selected input parameters are shown in Fig 3. At first glance it is clear that the three algorithms produced significantly different maps. Many inconsistencies regarding land component boundaries can be observed. This is supported by the results of the morphological discontinuity assessment (Table 2), which show that only 30.9 % of the reference points coincided with the unit boundaries of all three maps.

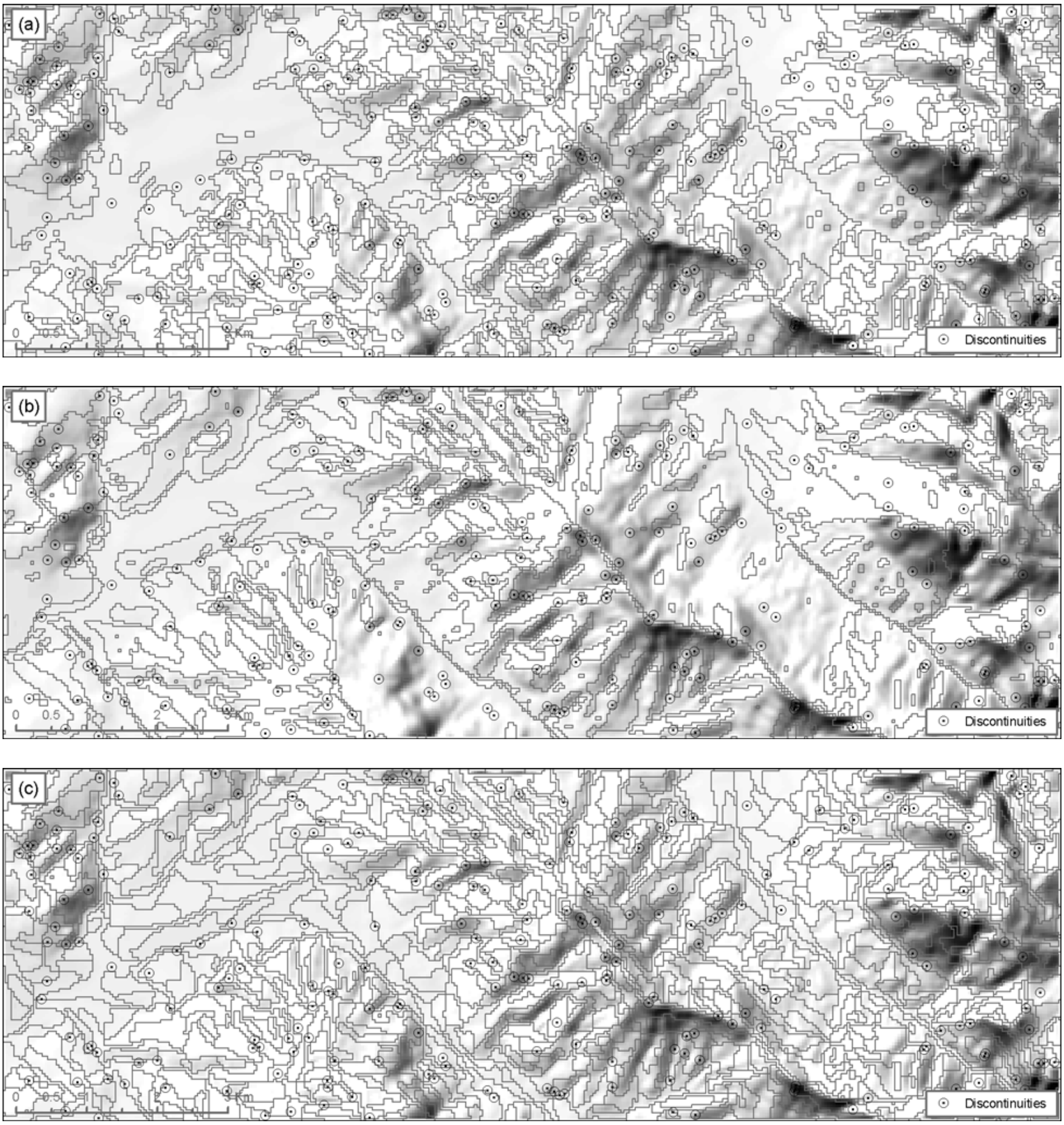

Figure 3 Land component maps produced by (a) ALCoM, (b) ISODATA and (c) MRS with the locations of reference morphological discontinuities shown (see Fig. 2).

Table 2 Number and percentage of interpreted morphological discontinuity points that coincide with land component boundaries of each algorithm.

Land component map	Coincidence (number of points)	Coincidence (% of points)
ALCoM	163	66.3%
ISODATA	76	43.5%
MRS	197	80.1%
Combined	76	30.9%

MRS performed the best at detection of morphological discontinuities, with 80.1 % of the reference discontinuities coinciding with its land component boundaries. ALCoM managed to delineate its units along only 66.3 % of the discontinuities, while ISODATA’s coincidence level is the lowest (43.5 %). In contrast, Fig 4a shows that the land components produced by ISODATA are the most homogenous, with 590 (58.8 %) of its units having a slope gradient standard deviation (SGSD) of less than 1°. This is substantially more than ALCoM and MRS, which respectively produced only 263 (23.9 %) and 199 (18.3 %) segments with such a small SGSD. Unlike ALCoM and ISODATA that generated progressively fewer land components as SGSD increases, the majority (55.7 %) of MRS land components has a SGSD of between 2° and 4°. A similar observation can be made in Fig 4b, where the largest proportion (87 %) of the units produced by MRS had a slope aspect mean vector strength (SAMVS) of more than 0.9, indicating a near-perfect concentration of slope aspect (Mardia and Jupp, 2000). In contrast, only 226 (27.3 %) of ISODATA’s units had a SAMVS of more than 0.9. Of the three algorithms, ALCoM produced the smallest proportion (0.2 %) of land components with an SAMVS of more than 0.9. Overall, with a mean SASD (MSASD) of 34.3° and mean SAMVS (MSAMVS) of 0.087, ALCoM produced the least homogeneous land components. Although ISODATA’s segments were slightly more homogeneous than MRS’s in terms of slope gradient, MRS’s land components are in general significantly more homogenous with a MSGSD and SAMVS of 1.9° and 0.946 respectively.

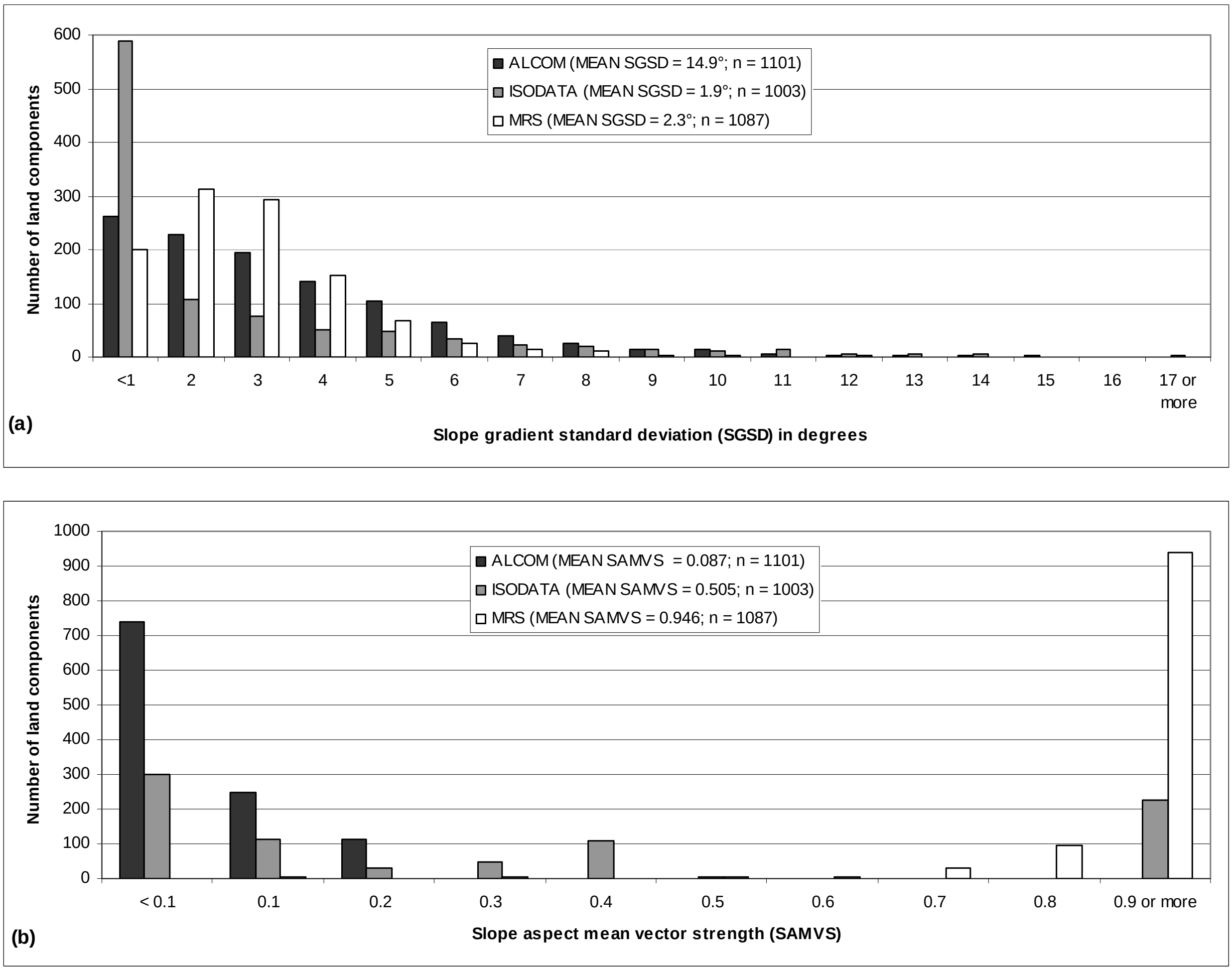

Figure 4 Histograms showing the (a) slope gradient standard deviation and (b) slope aspect mean vector strength of cells within land components.

The results of the internal homogeneity and morphological discontinuity assessments are somewhat conflicting in the case of ISODATA, as one would expect that the land component boundaries produced by an algorithm that generates the most homogenous segments in terms of slope gradient would have a high coincidence with terrain discontinuities. A possible explanation for this conflicting result is the sizes of the land components produced. While MRS-delineated land components are relatively uniform in size, the size of the land components generated by ISODATA range from very small (0.16 ha) to very large (817.6 ha). This observation is supported when the land component areas of all three maps are plotted on an exponentially-scaled graph (Fig. 5). The normal distribution (skewness: -1.3; kurtosis: 0.7) of land component areas produced by ALCoM suggests that it generated a good variation of land component sizes (standard deviation of 22.8 ha) with areas varying in size according to terrain complexity. ISODATA produced a highly skewed (9.6) histogram, with most land components having a size of 0.16 ha. It was found that 402 (40 %) of the land components produced by ISODATA have an area equal to one input grid cell (i.e. 0.16 ha). By contrast, only 11 (1 %) and 3 (0.3 %) single-cell land components were produced by ALCoM and MRS respectively. ISODATA is clearly less tolerant of small groupings of grid cells that differ in terms of slope gradient and aspect from their neighbouring cells. Tolerance to outliers is important for land surface segmentation as it prevents the creation of a large number of insignificantly small units. A large proportion of small units will not only increase computer processing times, but will also reduce overall terrain representation as more land components will be needed to adequately depict the landscape. The large proportion of very small units in the ISODATA map would also affect the calculation of internal homogeneity as a single-cell segment would always have a standard deviation of 0°. To determine how single-cell units influence on the homogeneity assessment, all such segments were eliminated from all three maps. Although no significant changes were observed for MRS and ALCoM, the land components produced by ISODATA were considerably less homogenous, with a MSGSD and a MSAMVS of 3.7° and 0.174 respectively. The level of slope gradient homogeneity of the modified ISODATA map is therefore similar to that of the MRS map, while its slope aspect is almost as variable as that of ALCOM.

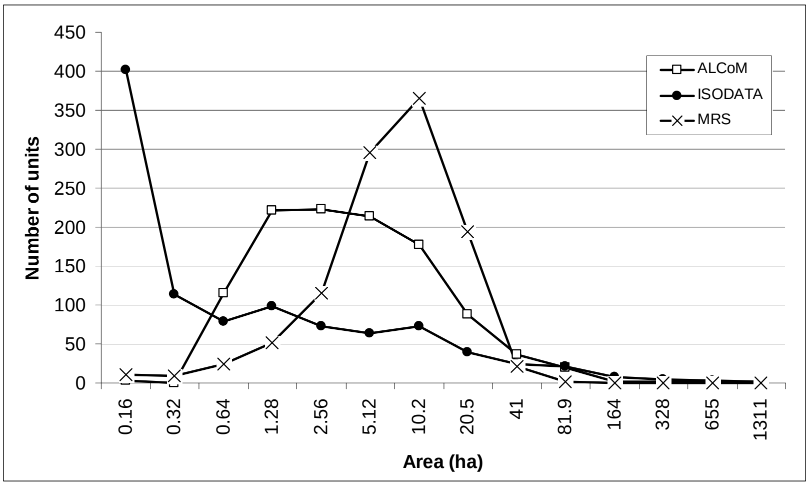

Figure 5 A comparison of land component areas indicating that ISODATA-produced units are predominantly smaller than one hectare, while ALCoM- and MRS-produced land components vary in size.

Discussion

The results show that none of the segmentation algorithms evaluated can be singled out as being superior in both homogeneity and morphological sensitivity. Although ALCoM managed to align its land component boundaries reasonably well with morphological discontinuities, it produced the least homogenous land components. A likely explanation for the latter is the deterministic way in which ALCoM delineates aspect regions. Although a possible improvement would be to increase the number of aspect classes used in the initial slope aspect regionalization, it will likely produce too many initial segments and consequently reduce the overall terrain representivity. While ISODATA produced significantly more homogenous land components than ALCoM, it performed poorly in the morphological discontinuity assessment. It also produced a large proportion of segments that were insignificantly small. This can be attributed to the sensitivity of ISODATA's clustering approach to outliers. Although such small units can easily be removed using filtering or aggregation techniques, such measures introduce an additional level of complexity to the land unit mapping procedure as the analyst will have to decide on an appropriate threshold for elimination. MRS produced relatively homogenous land components and was significantly more successful than the other two algorithms in detecting morphological discontinuities. A likely explanation for the latter is the way in which MRS uses local statistical measures to delineate segment boundaries. Although ALCoM also considers statistical measures (variability) to identify slope breaks within a local (i.e. aspect region) context, MRS does so without being restricted to fixed aspect region boundaries. This enables MRS to be more sensitive to local variations in slope gradient and aspect when delineating land component boundaries. In contrast to MRS and ALCoM, ISODATA clusters (groups) cells with similar properties irrespective of their relative locations. Because clusters often consist of a number of discontinuous regions (which are in many cases the size of a single cell), the boundaries of such segments are determined by the combined properties of all the segments within a cluster. The insensitivity of ISODATA to local variations in terrain often leads to the creation of inappropriate segmentation boundaries.

In general MRS produced the best overall results, with land components that are almost as homogenous as those of ISODATA when slope gradient is considered and significantly more homogenous than any of the other two algorithms in terms of slope aspect. The higher sensitivity of MRS to local variation in terrain was the likely reason why it produced land component boundaries that closely matched terrain discontinuities. It is also this sensitivity that produced more detailed components in areas of moderate terrain. This ability of MRS is invaluable for land evaluation as these areas are more likely to be affected by land use changes. MRS also has a number of other advantages over the other two methods. One, in particular, is the higher level of control that the analyst has over the segmentation process as it provides three additional settings that modify the way in which the algorithm delineates land components. While the *layer weight* parameter specifies the relative importance of each terrain property (i.e. slope gradient and aspect), the *shape* and *compactness* parameters can be used to define the shape of the resulting land components. However, more experimentation is needed to determine the effect of these different input parameters on MRS output. In addition, the MRS *scale* parameter used in this study was not necessarily optimal as it was purposely chosen to produce a particular number of land components for comparison purposes. Another factor that needs to be investigated is the effect of the input DEM's resolution and scale on the quality of the output. Guidelines regarding optimal MRS input parameters (i.e. scale, weight, shape and compactness) and DEM resolution are urgently needed as they will enable analysts to generate more realistic land component maps and ultimately make better decisions regarding land use.

Conclusions

Land components are frequently used in land evaluation as basic mapping units (i.e. land units). This research compared three techniques for delineating land components from a DEM and showed that segmentation algorithms have a significant effect on the size, boundaries and homogeneity of the resulting land components. The use of ISODATA to generate land units from DEM derivatives is not encouraged, as its land components rarely coincide with terrain discontinuities. This is mainly due to the way in which the algorithm groups input cells based on global (i.e. not local) clusters. Due to its inability to produce homogenous land components, ALCoM is also not recommended. Overall, MRS performed consistently well and was significantly more sensitive to morphological discontinuities than the other two methods tested. Land use managers should, however, use the technique with care as very little is known about how different input parameters and DEM properties influence the resulting segmentation. Nevertheless, the results show that the technique has the potential to generate land units that are highly suitable for land evaluations.

References

Adediran, A.O., Parcharidisb, I., Poscolieric, M., Pavlopoulosd, K., 2004. Computer-assisted discrimination of morphological units on north-central Crete (Greece) by applying multivariate statistics to local relief gradients. Geomorphology 58, 357-370.

Argialas, D.P., 1995. Towards structured-knowledge models for landform representation. Zeitschrift für Geomorfologie N.F 101, 85-108.

ASTER GDEM Validation Team, 2009. ASTER Global DEM Validation: Summary report [online]. Available from http://www.ersdac.or.jp/GDEM/E/image/ASTERGDEM_ValidationSummaryReport_Ver1.pdf [Accessed 7 Dec 2009].

Baatz, M., Schäpe, A., 1999. Multiresolution segmentation: an optimization approach for high quality multi-scale image segmentation. In Strobl, J., Blaschke, T., Griesebner, G. (Eds.) Angewandte Geographische Informationsverarbeitung 2000. Herbert Wichmann Verlag, Salzburg, pp.12-23.

Blaschke, T., Strobl, J., 2003. Defining landscape units through integrated morphometric characteristics. In Buhman, E., Ervin, S. (Eds.) Landscape modelling: Digital techniques for landscape architecture. Wichmann-Verlag, Heidelberg, pp.104-113.

Campbell, J.B., 2006. Introduction to remote sensing. Taylor & Francis, London.

Definiens Imaging, 2004. eCognition 4 User Manual. Definiens Imaging GmbH, Munich.

Definiens Imaging, 2007. Definiens Developer (version 7) user manual. Definiens AG, Munich.

Dikau, R., Brabb, E.E., Mark, R.M., 1991. Landform classification of New Mexico by computer. U.S. Department of the Interior. U.S. Geological Survey. Open-file report.

Dragut, L., Blaschke, T., 2006. Automated classification of landform elements using object-based image analysis. Geomorphology 81, 330-344.

Dymond, J.R., Derose, R.C., Harmsworth, G.R., 1995. Automated mapping of land components from digital elevation data. Earth Surface Processes and Landforms 20, 131-137.
ESRI, 2009. ArcGIS - The complete geographic information system [online]. Redlands: ESRI. Available from http://www.esri.com/software/arcgis/index.html [Accessed 13 August 2009].
FAO, 1976. A framework for land evaluation. FAO, Rome.
FAO, 1984. Land evaluation for development. FAO, Rome.
FAO, 1985. Guidelines: Land evaluation for irrigated agriculture. FAO, Rome.
FAO, 2007. Land evaluation: Towards a revised framework. FAO, Rome.
Gibson, P.J., Power, C.H., 2000. Introduction to remote sensing: Digital image processing and applications. Taylor and Francis, London.
Giles, P.T., Franklin, S.E., 1998. An automated approach to the classification of the slope units using digital data. Geomorphology 21, 251-264.
GISjobs.com, 2006. User survey [online]. Appleton: GISjobs.com, LLC. Available from http://www.gisjobs.com/survey/responses.jsp?countryLoc=all&sal=N [Accessed 10 February 2006].
Graff, L.H., Usery, E.L., 1993. Automated classification of generic terrain features in digital elevation models. Photogrammetric Engineering & Remote Sensing 59, 1409-1417.
Hall, D.J., Khanna, D.K., 1977. The ISODATA method computation for the relative perception of similarities and differences in complex and real data. In Enslein, K., Ralston, A., Wilf, H.S. (Eds.) Statistical methods for digital computers. John Wiley & Sons, New York, pp.340-373.
Hengl, T., 2006. Finding the right pixel size. Computers & Geosciences 32, 1283.
Irvin, B.J., Ventura, S.J., Slater, B.K., 1997. Fuzzy and ISODATA classification of landform elements from digital terrain data in Pleasant Valley, Wisconsin. Geoderma 77, 137-154.
Jenks, G.F., 1967. The data model concept in statistical mapping. International Yearbook of Cartography 7, 186-190.
MacMillan, R.A., Jones, R.K., McNabb, D.H., 2004. Defining a hierarchy of spatial entities for environmental analysis and modeling using digital elevation models (DEMs). Computers, Environment and Urban Systems 28, 175-200.
Mancas, M., Gosselin, B., Macq, B., 2005. Segmentation using a region-growing thresholding. Proceedings of the Electronic Imaging Conference of the International Society for Optical Imaging (SPIE/EI 2005), San Jose, USA.
Mardia, K.V., Jupp, P.E., 2000. Directional statistics. Wiley, New York.
Miliaresis, G.C., 2001. Geomorphometric mapping of Zagros Ranges at regional scale. Computers & Geosciences 27, 775-786.
Minár, J., Evans, I.S., 2008. Elementary forms for land surface segmentation: The theoretical basis of terrain analysis and geomorphological mapping. Geomorphology 95, 236.
NASA, 2005. Shuttle Radar Topography Mission [online]. Available from http://www2.jpl.nasa.gov/srtm/mission.htm [Accessed 13 May 2008].
NASA, 2009. ASTER Global Digital Elevation Model (GDEM) [online]. Available from http://asterweb.jpl.nasa.gov/gdem.asp [Accessed 9 Sep 2009].
Németh, T., Bidló, A., Gaál, Z., Heil, B., Hermann, T., Makó, A., Máté, F., Speiser, F., Szûcs, I., Tóth, G., Tóth, T., Várallyay, G., Vass, J., 2006. Framework and Components of a New Land Evaluation System in Hungary. The 18th World Congress of Soil Science (July 9-15, 2006), Philadelphia.
Rabus, B., Eineder, M., Roth, A., Bamler, R., 2003. The shuttle radar topography mission--a new class of digital elevation models acquired by spaceborne radar. ISPRS Journal of Photogrammetry and Remote Sensing 57, 241.
Rodriguez, E., Morris, C.S., Belz, J.E., Chaplin, E.C., Martin, J.M., Daffer, W., Hensley, S., 2005. An assessment of the SRTM topographic products. Jet Propulsion Laboratory, Pasadena.

Romstad, B., 2001. Improving relief classification with contextual merging. ScanGIS'2001 - The 8th Scandinavian Research Conference on Geographical Information Science, Ås, Norway.
Samranpong, C., Ekasingh, B., Ekasingh, M., In Press. Economic land evaluation for agricultural resource management in Northern Thailand. Environmental Modelling & Software In Press, Corrected Proof.
Speight, J.G., 1977. Landform pattern description from aerial photographs. Photogrammetria 32, 161-182.
Thakur, A., Anand, R.S., 2005. A local statistics based region growing segmentation method for ultrasound medical images. International Journal of Signal Processing 1, 141-146.
Thompson, J.A., Bell, J.C., Butler, C.A., 2001. Digital elevation model resolution: Effects on terrain attribute calculation and quantitative soil-landscape modeling. Geoderma 100, 67-89.
USGS, 2009. Earth Resources Observation and Science (EROS) [online]. Sioux Falls: USGS. Available from http://eros.usgs.gov/ [Accessed 15 Sep 2009].
Van Niekerk, A., Schloms, B.H.A., 2001. Automated mapping of land components from elevation data. Paper presented at the Fourth Biennial International Conference of the Society of South African Geographers, Rawsonville.
Van Niekerk, A., Schloms, B.H.A., 2002. A comparison of automatically mapped land components with large-scale soil maps. Paper presented at the Regional Conference of the International Geographical Union, Durban.
Ziadat, F.M., 2007. Land suitability classification using different sources of information: Soil maps and predicted soil attributes in Jordan. Geoderma 140, 73.