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A new methodology for measuring land fragmentation

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ABSTRACT

The presence of land fragmentation can indicate that an existing land tenure structure is problematic. It can be a major problem in many regions because it restricts rational agricultural development and reduces the opportunities for sustainable rural development although in some cases, it can prove beneficial and desirable for social and environmental reasons. Whilst policies to counter land fragmentation require reliable measurement of the situation, current fragmentation indices have significant weaknesses. In particular, they ignore critical spatial variables such as the shape of parcels as well as non-spatial variables such as ownership type and the existence or absence of road access for each land parcel. Furthermore, there is no flexibility for users to select the variables that they think appropriate for inclusion in the fragmentation index, and no variable weighting mechanism is available. The aim of this paper is to introduce a new 'global land fragmentation index' that combines a multi-attribute decision-making method with a geographic information system. When applied to a case study area in Cyprus, the new index outperforms the existing indices in terms of reliability as it is comprehensive, flexible, problem specific and knowledge-based. The methodology can be easily applied to assess the quality of any existing system for which evaluation criteria can be defined with values ranging from the worst to best conditions.

1. Introduction

Agricultural land fragmentation, also known as pulverization, parcellization and scattering (Bentley, 1987), is defined in the literature as the situation in which a single farm or ownership consists of numerous spatially separated parcels (King & Burton, 1982; McPherson, 1982; Van Dijk, 2003) which may be small in size and have irregular shapes. However, this type of land fragmentation is associated with problems which involve a defective land tenure structure and generally with factors that prevent landowners from exploiting their ownerships. In particular, in Cyprus, there are additional land fragmentation factors such as the lack of road access to land parcels in certain areas and issues relating to ownership rights. For instance, a parcel may be owned in undivided shares (shared ownership), i.e. it may belong to more than one landowner, or there may be dual or multiple ownership, i.e. the land is owned by one person whilst the trees growing on the land are owned by someone else and a third party has ownership rights for water.

King and Burton (1982) characterise land fragmentation as a fundamental rural spatial problem concerned with farms that are poorly organised at locations across space. Similarly, many authors (e.g. Blaikie & Sadeque, 2000; DeLisle, 1982; Jabarin & Epplin, 1994; Karouzis, 1971) consider land fragmentation as a serious obstacle to optimal agricultural development because it hinders mechanisation, causes inefficient production and involves large costs to alleviate the adverse effects, resulting in a reduction in farmers' net incomes. This situation is even more pronounced today because of increased agricultural market competition and the industrialization of the agricultural sector.

Although the term has these negative connotations that are the focus of this paper, land fragmentation is not necessarily a problem in all cases (Bentley, 1987; Van Dijk, 2003) and there are sometimes benefits relating to risk management, crop scheduling and ecological variety. Farmers have to minimise the potential risk of climatic and natural disasters and having dispersed parcels may be one solution (Bentley, 1987; King & Burton, 1982; Tan, Heerink, & Qu, 2006; Van Hung, MacAulay, & Marsh, 2007). Risk is also reduced through a greater variety of soils, crops and growing conditions when several locations are being used (Van Hung et al., 2007). Crop scheduling occurs when parcels are scattered between various locations at different altitudes so that crops mature at different times. Ecological variety is realised through the formulation of a natural mosaic of parcel shapes, crops and colours. In addition, some social reasons favour the existence of land consolidation such as communities where the self-sufficiency of families for food is a necessity.

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Land fragmentation is evident in many areas throughout the world. In particular, whilst land fragmentation has been closely associated with Europe and Mediterranean countries (e.g. Falah, 1992; Karouzis, 1971), it is a topic that has been studied in many other countries and regions around the world (e.g. Blaikie & Sadeque, 2000; Goland, 1993; Kjelland et al., 2007; Nguyen, Cheng, & Findlay, 1996; Ram, Tsunekawa, Sahad, & Miyazaki, 1999; Soltow, 1983; Verry, 2001; Wan & Cheng, 2001). FAO statistics from 1986 to 2004 for six continents reveal that the smallest average holding size is found to be less than 5 hectares (ha) in 20 out of 24 Asian and 16 out of 20 African countries respectively. In almost half of the Central American and Oceania countries, the average holding size is less than 5 ha. In contrast, 10 out of 10 South American and 23 out of 28 European countries have an average holding size greater than 5 ha. Regarding Europe, the problem has been identified by many researchers (Bentley, 1987; Burton & King, 1982; Van Dijk, 2003) which several of them focus on particular EU countries such as Cyprus (Burton & King, 1982; Karouzis, 1971); Portugal (Bentley, 1990); Greece (Keeler & Skuras, 1990); Czech Republic (Sklenicka & Salek, 2008); Romania (Rusu, 2002); Bulgaria, Germany, Hungary, Romania and Slovenia (Thomas, 2006). European Commission's (2000, 2003, 2005) statistics show that although the average agricultural area per holding considerably varies within the EU, the distribution of holdings by size class indicates that the large majority of European holdings (in 2003) are relatively small in size since 75.7% of all holdings across the EU-27 use less than 5 ha.

Although the causes of land fragmentation vary from country to country and from region to region, there is general agreement that there are four main factors that trigger fragmentation: inheritance; population growth; land markets; and historical/cultural perspectives (Bentley, 1987; King & Burton, 1982; Niroula & Thapa, 2005; Tan et al., 2006; Van Hung et al., 2007). Other factors noted in more specific situations include: social and administrative decrees (Bentley, 1987); long-established cultivation; shortages of land and nucleated settlement; the piecemeal conversion of forests and moorland to arable land (Grigg, 1980); and the privatisation transition process, e.g. in ex-eastern block and central European countries (Van Dijk, 2003). Depending on the cause, different policies are adopted for controlling land fragmentation that can be divided into three categories: legislation restrictions (Niroula & Thapa, 2005), land management approaches such as land consolidation (Thomas, 2006; Vitikainen, 2004) and land protection policies/programmes (Brabec & Smith, 2002). Although taking policy decisions requires a comprehensive study of the impacts of land fragmentation, decision makers and planners very often need a reliable indicator for quantifying the land fragmentation problem at the ownership level.

Decisions on applying certain land management measures to control fragmentation usually involve undertaking a land fragmentation study, an environmental impact assessment and a feasibility study. The outcome of the former can be represented by an appropriate index. However, there appears to be no standard or comprehensive measure of land fragmentation (Bentley, 1987; Van Hung et al., 2007). Specifically, most authors have utilised a simple univariate fragmentation measure such as the average number of parcels per holding or the average holding size or the average parcel size at the regional or national level. More complex indices were developed in the 1960s and 1970s that incorporate more than one factor (e.g. Dovring, 1965; Edwards, 1961; Igbozurike, 1974; Januszewski, 1968; Simmons, 1964; Schmook, 1976) which remain partial at best as they do not take all of the relevant factors into account (Monchuk, Deininger, & Nagarajan, 2010). Current indicators appear to ignore non-spatial factors such as the ownership type for each parcel and the existence or absence of road access to a parcel, which may completely prevent parcel exploitation. Furthermore, there is no flexibility for the user in the selection of variables used in the fragmentation index, and there is no mechanism to allocate different weights to the factors selected. Moreover, other indices have been developed specifically for ecological land fragmentation (McGarigal & Marks, 1995) which are not appropriate, however, for agricultural land fragmentation. Therefore, these limitations clearly indicate the need for a new methodology for measuring land fragmentation (Demetriou, Stillwell, & See, 2011b).

Thus, in this paper we present a new methodology for measuring land fragmentation. This approach might be valuable, for example, when considering the application of land consolidation measures (or other related measures) in a certain area. The methodology links multi-attribute decision making (MADM) with a geographic information system (GIS) to build a model called LandFragmentS (Land Fragmentation System) (Demetriou et al., 2011b), which is a subsystem of LACONISS (LAnd CONsolidation Integrated Support System for planning and decision making) (Demetriou, Stillwell, & See, 2012a; Demetriou, 2013). The new method results in a 'global land fragmentation index (*GLFI*)' which is implemented in a case study area in Cyprus and outperforms existing indices. It is comprehensive since it takes a number of basic land fragmentation parameters into account; it is flexible and problem specific in that the user may select which factors need to be included for a specific area under investigation and may assign a different weight to each factor representing its importance to the problem at hand; and it is knowledge-based by incorporating expert judgment through the definition of value functions (Beinat, 1997) for the criteria involved. A broader contribution of this research is that the methodology can be easily applied to assess the quality of any existing system for which evaluation criteria can be stipulated that have values ranging from the worst to the best conditions.

2. Measuring land fragmentation

2.1. Problems in agriculture associated with land fragmentation

Fig. 1 shows a cadastral plan of a highly fragmented area in Cyprus. It is apparent that the parcels are small with irregular shapes and many have no access to roads. Moreover, the figure shows an example of 19 dispersed parcels that belong to a single landowner who owns a further eight shares in other parcels dispersed throughout the area. According to Bentley (1987), the discussion about the dispersion between parcels of a given holding and in particular the distance from the farmstead began in 1826 with the publication of Johan Von Thunen's 'The Isolated State', whose argument was based on the premise that the costs of farming increase with distance. In particular, when parcels are spatially dispersed, then the travel time and hence the costs in moving labour, machines *et cetera* from one parcel to another are increased (Bentley, 1987; Burton, 1988; Karouzis, 1977; Niroula & Thapa, 2005) and therefore parcels at a greater distance are cultivated less intensively (Van Dijk, 2003). Many case studies have proved the consequences of this problem in practice (DeLisle, 1982; Karouzis, 1971).

Small parcel size and irregular shape are the dominant problems of land fragmentation. The use of modern machinery becomes more difficult or could be impossible on tiny parcels and may require an excessive amount of manual work in the corners and along the boundaries (Bentley, 1987; Burton, 1988; Karouzis, 1977, 1980). Furthermore, irregular parcel shape prevents the proper cultivation of the land, especially for some crops (e.g. vines, olives) which need to be cultivated in rows or series. Moreover, the implementation of soil conservation measures is difficult, the construction costs are higher, more fencing is needed, and roads, which are usually adjusted to the shape of the parcels, have low geometrical (horizontal and vertical) standards, meaning that they