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Determination of agricultural soil index using geostatistical analysis and GIS on land consolidation projects: A case study in Konya/Turkey

Mevlut Uyan

Selcuk University, Directorate of Construction & Technical Works, Konya, Turkey

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ABSTRACT

Land consolidation (LC) is a technical process for agricultural parcels rearrangement according to developing agricultural technology and a gate for sustainable rural development. The success of LC projects depends on the correct determination of soil index (SI) for each of the agricultural parcel. SI values for all study area are determined by interpolation methods using observed SI plots. The spatial analysis based on the kriging method is a convenient and strong way for the estimation of the unknown points from the known points.

The purpose of this study was to determine and evaluate the agricultural SI using ordinary kriging with GIS technology for LC projects. Spatial continuity of SI values was calculated using an experimental variogram. The performance of six models (Circular, Spherical, Tetraspherical, Pentaspherical, Exponential, Gaussian) have been compared. Spatial structure of SI values was better explained using exponential models. Nugget-sill rate can be used in the classification of the spatial dependency. The nugget-sill ratio was showed high dependency with 0.21. The average range of variogram (exponential model) for the spatial analysis is about 5815 m. Results of ordinary kriging for SI values were underestimated by 11%. The estimations obtained for SI were represented in a map. The results of the ordinary kriging based SI values were compared with the results of the prepared SI map by classical methods for some agricultural parcels.

1. Introduction

The agricultural sector is the primary source of economic activity for rural areas in Turkey. With its favorable geographical conditions and climate, Turkey is considered to be one of the leading countries in the world in the field of food and agriculture. Turkey has a large and growing food and agriculture industry that corresponds to 9% of the overall gross value-added (GVA) and 25% of the employment levels in the country (Uyan et al., 2015).

8.5 million ha of land can be economically irrigated in Turkey. However, only 4.8 million ha of land are being irrigated at present. The average farm size was 10 ha in 1950, 6.8 ha in 1980, 5.9 ha in 1990 and 6.1 ha in 2001; the numbers of farms in the same years were 2.2 million, 3.5 million, 3.9 million and 3.02 million respectively. The average parcel number per landholding is 4.08, according to the results of the General Agricultural Census in 2001 (Cay et al., 2010).

Agricultural land fragmentation is a common phenomenon in developing countries (Latruffe and Piet, 2014). Land fragmentation is the biggest problem to sustainable agriculture. To prevent these problems, legal and juridical arrangements are made in order to prevent more fragmentation and alteration, and also to heal already existing decrements, fragmentation and disorder (Uyan et al., 2013). The major cause of land fragmentation in Turkey over the past has been population pressure on land. Turkey loses $10 billion annually because of fragmented agricultural fields. Land consolidation (LC) is the most favorable land management approach for solving agricultural land fragmentation (Uyan et al., 2015).

LC is regarded as an instrument or entry point for rural development and an important means to solve land use problems in increasing food production capacity, reconciling land use conflict, improving landowners' relation, boosting rural development (Guo et al., 2015; Niroula and Thapa, 2005). LC in rural areas not only aims at combining fragmented parcels but also better management of all related areas such as agricultural, technical, social and cultural areas to improve standards of land ownership (Cay and Uyan, 2013; Cay et al., 2010; Pasakarnis and Maliene, 2010). LC has been applied in many countries around the world, of which the content varies substantially from one country to another (Guanghuia et al., 2015).

In Turkey, while only 450,000 ha of fragmented agricultural land were consolidated from 1961 to 2002, 5 million ha of

E-mail address: muyan@selcuk.edu.tr

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fragmented agricultural land were consolidated between 2002 and 2013. The aim is to consolidate 5 million ha of fragmented agricultural land between 2013 and 2017.

LC projects basically go through the following technical phases (Uyan et al., 2013);

- Provide of property information of all farms and landowners.
- Creation of agricultural soil index (SI) maps.
- Preparation of new block plans which match with road, irrigation and drainage networks.
- Asking landowners their opinions.
- New percolations planning – in other words land reallocation.
- Creation of new registries for finalized new plans by cadastre.

LC projects consist of various steps, within which the land reallocation stage is the core of consolidation. Reallocation quantity depends on the SI of agricultural land. For SI, the expert-surveyor, with a delegation of the local commission and all persons who know the land, goes on the terrain to observe the parcels and to classify them (Derlich, 2002). The purpose of this stage is to ensure equivalent that the new parcels will be given to the landowners after LC with their previous parcels. It is extremely important for the success of LC.

Geostatistical approaches can provide more helpful, reliable and efficient tools to increase the number of measurement points at unsampled locations, and variogram analyses for examining structural relationship of data (Uyan and Cay, 2013). The kriging interpolation is regarded as the optimal interpolation and is the most widely used in geostatistics. It estimates an unknown point by making use of a known point. Geostatistical results using kriging techniques are more efficient when data for variables are distributed normally (Wu et al., 2014, 2010; Uyan and Cay, 2013). Geographic information system (GIS) is a technological field that incorporates geographical features with tabular data in order to map, analyze, and assess real-world problems. The real power of GIS is through using spatial and statistical methods to analyze attribute and geographic information. The end result of the analysis can be derivative information, interpolated information or prioritized information.

Geostatistics and GIS technologies have been used a management and decision tool by many researchers for the agricultural researches. For example, estimation of croplands (da Silva et al., 2015; Desiato et al., 2014), determination of agricultural field boundaries (de Bruin et al., 2008; Moral et al., 2011; Chang et al., 2014), evaluation of soil quality (Wang and Shao, 2013; Robinson and Metternicht, 2006; Yang et al., 2009).

For fast and efficient progress in projects, usage of computer technology has been essential. In Turkey, computer support for the agricultural land valuation is not frequently considered in LC projects. The incorporation of geostatistics procedures in agricultural studies based on kriging techniques has been used in several areas of science. The incorporation of these procedures into geographic information systems (GIS) has triggered a new phase in the development of conceptual methods of cartographic representation. The association of GIS and geostatistics enhances the traditional procedures of such systems, including image classification, due to the high quality of the estimator (da Silva et al., 2015). The purpose of this study was to determine and evaluate the agricultural SI using ordinary kriging with GIS technology for LC projects.

2. Material and methods

2.1. Study area

The research area was chosen as the village of Yollarbası in the Karaman Province, Turkey. It is situated 15 km in Karaman. The SI data were determined from 109 observation points (Fig. 1). Study area is approximately 5680 ha. The agricultural lands in the study area are bigger than those in many other parts of Turkey. The topographical structure is generally flat and close to flat. The cultivated products are mostly wheat, barley and chickpea.

Documents of cadastral parcels, SI data and other information on the area were obtained from the Agricultural Reform Regional Directorate (TRGM).

2.2. Soil sampling

LC projects are performed by two different law and legal institutions. If an LC study area is in the application areas of agrarian reform, it is performed by the Directorate General of Agrarian Reform (TRGM), according to Land Reform regarding rearrangement of land in irrigated areas (Law no. 3083, date: 1984). Other areas are performed by Special Provincial Administration, according to Soil Conservation and Land Use Law (Law no. 5403, date: 2005). In this study, LC was performed according to Law no. 3083 (Land Reform Regarding Rearrangement of Land in Irrigated Areas Law). For SI values, the expert-surveyor goes on the terrain to observe the agricultural areas with some methods.

Soil index based on solely the soil characteristics and is obtained by evaluating factors such as soil depth, structure of the surface layer, subsoil characteristics, drainage, salinity, alkalinity, pH, erosions and relief. Soil index is rated productivity capabilities, potential benefit opportunities according to the land of the soil characteristics. SI is marked as 100 points.

Soil index is calculated according to the following formula:

$$\mathrm{SI} = A * B * C * X \tag{1}$$

where A is the topsoil profile group (the kind of main material, shape and accumulation formation, age of soil material, variation, erosion resistance), B is the topsoil texture (sand, silt and clay rates according to various size groups in topsoil), C is the land slope and X is the soil profile group (drainage, salinity, alkalinity, acidity, toxicant and erosions). In this study, the SI data were determined from 109 observation points by the expert surveyor.

2.3. Geostatistical analysis

Geostatistical theory is based on a stochastic model which allows the derivation of optimal predictions at random points in the study region. It allows us to take into account spatial correlation between neighboring observations and includes different approaches spanning from conditional estimator to simulation, either parametric or indicator approach. Advantage of geostatistics is the use of quantitative measures of spatial correlation, commonly expressed by variograms (Uyan and Cay, 2013). The semivariogram is the geostatistical method to find the presence of correlation between the samples. The semivariograms are the best method to characterize the structure of spatial continuity (Acerbi Junior et al., 2015). A semivariogram was calculated for each catchment using the average squared difference between all pairs of values which are separated by the corresponding distance lag. It is calculated according to the following formula (Chiverton et al., 2015):

$$\gamma(h) = \frac{1}{2(N-h)} \sum_{i=1}^{N-h} \left[Y(t_{i+h}) - Y(t_i)^2 \right] \tag{2}$$

where h is the lag distance, $Y(t_i)$ is the value of the transformed data at time t_i and $(N-h)$ is the number of pairs with lag distance h. A maximum lag distance over which to calculate the semivariogram was defined to enable the clustering to capture differences in the temporal dependence structure.