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# Land suitability procedure for sustainable citrus planning using the application of the analytical network process approach and GIS

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ABSTRACT

Land use planning and ecological land evaluation are considered the most important tools and factors of sustainable development. Two aspects are of importance, firstly the potential suitability of the land for a specific use and the secondly management practices that integrate various factors such as agro-ecological aptitude, environmental impact, hydro-climate conditions and socio-economic constraints. The aim of this paper is to identify the variety of interactions, dependencies and feedback between higher and lower level factors, and the impact of these interacting factors on sustainable citrus production. This new framework incorporates three-discipline criteria: socio-economic status, topography and hydro-climate. In this proposed multi-criteria model, the Analytic Network Process (ANP) enabled us to consider interdependency among the 14 different criteria. Based on experts' opinion weights were assigned to each of these 14 different criteria and using the ANP and GIS–MCDM, potential areas based on the most important, or limiting factors were determined. The results of this land suitability procedure (LSP) indicate a number of critical factors, which would help managers to achieve optimum crop yield and decrease the loss of citrus production. According to experts' opinion, higher weights were assigned to minimum temperature and altitude than to all other criteria. The results also demonstrate that climate conditions, and topography play a major role in potential citrus expansion. Suitable regions (free risk areas) for citrus production were identified based on major environmental factors and an optimum suitability map was obtained by overlaying 14 GIS layers. This map will be of value for future citrus planning decisions; and could lead to reduction in citrus investment and expansion into high-risk areas.



## 1. Introduction

Citrus L. (Rutaceae) is one of the most important commercial fruit crops of the world and Iran, which includes some of the major fruit species, such as *C. reticulata* Blanco (mandarin), *C.* × *aurantium* L. (sour orange), *C.* × *sinensis* (L.) Osbeck (sweet orange), (Swingle and Reece, 1967; Mabberley, 2004).

Sustainable food production for a rapidly growing human population is one of the major challenges faced by the agriculture sector globally (Godfray and Garnett, 2014; McClung, 2014). Hence, sustainable agriculture is now a major priority for environmental managers and requires the development of more productive, profitable, resource efficient and environmentally friendly farms.

Furthermore, land evaluation is a process of predicting land performance over time according to the specific types of use (Martin and Saha, 2009; Sonneveld et al., 2010). The principle purpose of agriculture land suitability is to predict the potential and limitation of the land for crop production (Pan and Pan, 2012).

Agricultural production activities are the foundation of human survival and development. Hence, a number of researchers have been active in this field recently (Le Gal et al., 2011; Nikkilä et al., 2012; Cardín-Pedrosa and Alvarez-López, 2012; With the growth in the population and the reduction of arable lands, ensuring effective use of arable land to meet the growing demand for food requires rational land use management and planning. Land suitability evaluation (LSE) involves the process of appraisal and grouping of specific areas of land in terms of their suitability according to the specific types of use (Rossiter, 1996; Liu et al., 2006; Lee and Yeh, 2009; Martin and Saha, 2009). Much progress

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has been made over the last twenty years in developing methods of multi-criteria-LSE, especially by integrating GIS with Multi criteria decision making (MCDM) (Malczewski, 2006; Mendas and Delali, 2012; Nguyen et al., 2015). The ANP is applied to determine the relative weights of the evaluative criteria. Recently, ANP is one of the most popular methods to obtain criteria weights for use in MCDM (e.g. Jung and Seo, 2010; Yang and Tzeng, 2011; Shiue and Lin, 2012; Saaty and Vargas, 2013; Liang et al., 2013; Aragonés-Beltrán et al., 2014; Jaafari et al., 2015). Additionally, ANP has been employed in the GIS-based MCDM (e.g., Pourebrahim et al., 2010; Huang et al., 2011; Sadeghi-Niaraki et al., 2011; Bojórquez-Tapia et al., 2013; Ferretti and Pomarico, 2013; Azizi et al., 2014). It calculates the required weights associated with criterion map layers with the help of a preference matrix, in which all identified relevant criteria are compared against each other based on preference factors.

In 1996, the Food and Agriculture Organisation (FAO) defined land-use planning as the systematic assessment of land and water potential, land-use alternatives and socio-economic conditions in order to adopt the best land-use options (FAO, 1996). The definition highlighted the ecological, socio-economic and environmental aspects that need to be taken into account in the planning process. Land evaluation has always been considered a core component of land-use planning (FAO, 1996; Roetter et al., 2005; Baja et al., 2007). The procedure, aimed at evaluating the potential of a given location for a particular land use, involves a set of quantifiable spatial criteria, their standardization functions, techniques for expressing preferences regarding the relative importance of the criteria, and aggregation rules combining quantified criterion preferences with standardized criterion values into an overall suitability score (Lodwick et al., 1990; Malczewski, 2004). Until now, instead of analytic hierarchy process (AHP), the integration of GIS techniques and ANP approach has received only minimal attention in MCDM studies, although this situation is changing (Nekhay et al., 2009; Ferretti and Pomarico, 2013; Azizi et al., 2014; Soltani et al., 2015). It should be noted that the most critical shortcoming of GIS combined with ANP is a comprehensive insight into sustainable agriculture planning. GIS–MCDA in general combines multicriteria decision analysis techniques – such as Saaty's (2001) Analytic Network Process – and GIS-based procedures are used to transform spatial data into an appraisal of a territory for specific purposes (Malczewski, 2004, 2006). Few studies have attempted to develop a GIS combined with ANP analysis for MCDM to determine sustainable crop production for future planning.

To the best of our knowledge, this study presents a novel and comprehensive approach in terms of sustainable citrus production in that no other studies have examined the combination of three main mother criteria including hydro-climate, topography and socio-economic using the application of ANP and GIS techniques for choosing suitable regions regarding optimum citrus growing regions. Therefore, this paper aims to fill this gap in the research.

This study also extends our perspective into sustainable citrus planning with expert knowledge related to suitability of a given area that provides an important guideline to achieve an optimum citrus production program.

We highlight ANP applications using GIS techniques for optimum crop production monitoring. The purpose is to provide the necessary background to fully understand the requirements of these applications.

Wu et al. (2011) conducted a study on citrus growing regions, and used (GIS) to investigate the growing conditions of citrus orchards in China. They assume the general guidelines for sustainable citrus production based on the topography and soil properties of the citrus orchards. The results of regional planning indicated suitable and potential cultivation areas for citrus growth. A GIS-based database management system also provided a new perspective on the management and planning of citrus orchards.

Das et al. (2009) reported an assessment of citrus crop condition using remote sensing (RS) and GIS techniques. The study mapped areas prone to citrus productivity based on the integrated effect of soil erosion, vegetation condition, and moisture stress.

Malik et al. (2013) dealt with a study on socio-economic importance, domestication trends and conservation of wild citrus species. The results of the study documented the socio-economic importance, horticulture potential and domestication trends of these wild and semi-domesticated species of citrus.

Barkataky et al. (2013) investigated the plant water requirement of 'Hamlin' sweet orange in cold temperature conditions. The objective of their study was to determine the effect of various temperature regimes on water use of sweet orange. The findings of this study suggest cold temperatures, irrespective of the duration, increase stomatal closure and root resistance, decreasing plant evapotranspiration (ET). Therefore, effective irrigation scheduling based on crop demand could save considerable quantities of water while providing adequate water for maintenance of quality citrus yields. The quality of citrus fruits obviously depends to a large extent on factors deriving from the nature of the fruit itself (provenance, type of soil, hydro-climate and citrus varieties).

This study explores optimization of land evaluation by combining different criteria using ANP and GIS in order to generate better strategies and advantages. Thereby, the current method also tends to be comprehensive with a high dimension.

## 2. Material and methods

### 2.1. Study area

This study was carried out in the Ramsar district which is located in the northern part of Iran about 250 km north of the capital of Iran (Fig. 1). The Ramsar region is located in the western part of the Mazandaran province, bordering the Caspian Sea to the north and the Alborz Mountains range to the south. The population was approximately 70,000 at the end of 2010 census (statistical center of Iran, 2010). This region is one of the most important producer regions in Iran, with approximately 6600 hectares of citrus orchards (Ramsar Agriculture Organization, 2013). The geographic coordinates of the study area are located between latitudes 36°32′00″ to 36°59′11″ N and longitudes 50°20′30″ to 50°47′12″ E. The total study area covers approximately 729.7 $km^2$. The altitude of Ramsar County starts at a height of −20 m near the Caspian Sea to 3620 m above sea level, where the climate is typically Mediterranean with warm and dry summers, and the main rainfall episodes occur from September to December. The mean annual precipitation of Ramsar is 1193.5 mm and the mean annual temperature is 17.6 °C (Ramsar Meteorological Administration, 2013).

### 2.2. Analytical network process

Various multi-criteria decision making (MCDM) methods have been used for site selection, including the Analytic Hierarchy Process (AHP) and Analytic Network Process, ANP (Saaty, 1996, 2005). In contrast to the hierarchy in AHP the ANP uses a network with inner and outer dependences without the need to specify the location in the levels, and permits the representation of the identified relationships between intangible assets and strategic objectives. Therefore, The ANP framework allows the elucidation of more complex interdependent relationships among elements, and enables prioritization of all alternatives and criteria with respect to each other and to develop their corresponding preferences.