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

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A B S T R A C T
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
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; Shihue and Lin, 2012; Saaty and Vargas, 2013; Liang et al., 2013; Aragonés-Beltrán et al., 2014; Jafarif et al., 2015). Additionally, ANP has been employed in the GIS-based MCDM (e.g., Pourrebahrami 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., 1999; 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–MCDAs in general combine 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, horticultural 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 km². 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.
The ANP has been used for Multi criteria decision making, MCDM, for project selection (Lee and Kim, 2000; Meade and Presley, 2002; Nilashi et al., 2014), product planning (Karsak et al., 2003; Sarkis, 2003; Lin et al., 2008), and strategic decision (Leung et al., 2006; Wu and Lee, 2007a,b).

The main reason we chose the ANP as our methodology for selecting the location operations is due to its suitability in offering solutions in a complex multi-criteria decision environment.

In general, the ANP application can be categorized into three different classes based on their fundamental purposes:

1. to model decision problems in order to select the best alternative with conflicting and interrelated criteria;
2. to analyze an existing framework by prioritizing the interrelated elements within the framework (Asan and Soyer, 2009; Yüksel and Dagdeviren, 2007);
3. to capture indirect influences of various elements and their relative significance on one another within the network (Lee et al., 2010).

Additionally, ANP is a mathematical theory that can systematically overcome all kinds of dependencies. The first step of the ANP is to set up a pair-wise comparison of the criteria. The relative importance value can be determined assuming a scale of 1–9 to represent equal importance to extreme importance (Saaty, 1980, 1996). The general form of the supermatrix, the consistency test method, and comparison matrices are widely described by Ergu et al. (2014).

In this study, the ANP model is employed for measuring the interdependence of 14 strategic factors assisting in the decision making process. The 14 crucial variables are divided into three groups: socio-economic status, topography and hydroclimate perspectives (Fig. 2). Topography included altitude, aspect and slope; hydro-climate included minimum temperature (Min-Temp), maximum temperature (Max-Temp), relative humidity (RH), growing degree days (GDD), rainfall, sunshine hours and water availability (spring well and river); socio-economic status included distance to roads and population areas respectively.

Finally, spss software version 20 were used to obtain the mean value of the input layers for each suitability zone displayed to see the variation of growth conditions in each zone.

2.3. Data collection

To collect expert information on citrus a questionnaire was send to 30 experts’ from the Iran Citrus Research Institute (ICRI) and to 10 experts from other organization. These experts were chosen according to their professional activities on citrus production and in the field of ecology–climatology. The various factors of the questionnaire have been extracted through the literature review and experts’ opinions. The sections of the questionnaire include 14 factors that affect citrus production.

The questionnaire used is based on Saaty’s model (1996), and included 47 questions. Here, the pair-wise comparison is employed because it provides more meaningful information for the assignment of weights to the various elements. These pairwise elements are then utilized to make comparative judgments in order to ensure the accuracy. In this sense, a measurement with many pairwise comparisons is made more scientifically than by assigning numbers more or less arbitrarily through guessing (Saaty, 2005). It is common to use the 9-point priority scale of absolute numbers (Table 1) for estimating the relative importance between paired elements (Saaty, 1980).

The data retrieved from the completed questionnaires were loaded into the Super Decision Software version 2.2 in order to calculate the relative weights of the various elements of the matrices and the consistency ratio (CR) employed for locating the inconsistent ratings. The development of weights is based on a pair-wise comparison matrix, with the sum of the weights being equal to one. The comparisons concern the relative importance of two
criteria involved in determining suitability for the stated objective. Fig. 3 gives a schematic sample of pair-wise comparison in this study. The importance of alternatives (classes) is only evaluated with respect to impacts on other alternatives.

The rate and/or weights of factors with respect to chosen criteria that are assigned by experts’ opinions were analyzed using super decision software to get final weighted, unweighted and limit matrix in terms of importance of criteria. Weights assignments are based on the effectiveness of the criteria. Hence, the results of limited matrix demonstrate the relative importance weights for every factor in the model. Limited matrix was obtained by calculating the square of each weighted supermatrix to powers by multiplying by times itself to capture the overall priorities of the factors.

To derive the importance or priorities for the criteria, certain factors need to be satisfied. Based on the significances of the various criteria and using ANP the best alternative which meets any requirement is determined. Assume that there are \( n \) factors, namely \( A_1, \ldots, A_n \) and each associated with a corresponding weight \( w_1, w_n \) respectively. Now, suppose a matrix of pairwise ratios is formulated in such a way that its rows are the weights of the individual stones with respect to all others, then the ANP model can be utilized to depict the underlying interdependence within the scenario:

\[
\begin{pmatrix}
A_1 & w_1/w_1 & \ldots & w_1/w_n \\
\vdots & \vdots & & \vdots \\
A_n & w_n/w_1 & \ldots & w_n/w_n
\end{pmatrix}
\]

The ANP model also includes a consistency test, to assess the degree of consistency of the decision maker. Saaty (1980) reported that the \( k_{\text{max}} \) must be equal to \( n \) in order for consistency to be met. This computation is afforded using the Consistency Index (CI) of the relation:

\[
CI = \frac{c_{\text{max}}}{C_0}
\]

(2)

In this way, the inconsistency ratio (CR) of CI is given by:

\[
CR = \frac{CI}{RI}
\]

(3)

where \( k_{\text{max}} \) value is an important validating parameter in ANP and is used as a reference index to screen information by calculating the Consistency Ration (CR) of the estimated vector. Additionally, \( k_{\text{max}} \) is the largest eigenvalue of a given matrix.

Following the collection of the results of the questionnaire from the 40 experts’ opinions, the average weight of the 14 factors was considered using ANP framework in super decision software and used for paired criteria comparison. In reality, the comparison of all criteria with respect to the parent node was done by experts in the form of a matrix. Then the matrix values should be normalized, meaning for each record, the value is divided by the sum of the respective column and the average calculated for the corresponding row.

These averages provide an estimate of the relative weights of the criteria being compared. This is the process of normalization. It must be done for all matrices. In the first step, all 14 data layers are added in ArcMap. Finally, to obtain a weighted linear combination map, each layer in the GIS environment needs to be multiplied by its corresponding weights.

Table 1: Critical criteria in ANP framework in super decision software.
In the next step, all layers and variables should be multiplied by their normalized weight (achieved from questionnaire by ANP analysis) in map algebra expression and then raster calculator is used to create the final map. In this step, the weight of each criteria multiple on own layer and added to other layers. Weighted overlay is used as a technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis (Malczewski, 2004). Finally, the result of the procedure is a land suitability map. The process of raster calculator was done in ArcGIS as shown in Fig. 4.

Consequently, the final result is a suitability map that represent areas from suitable to not suitable for citrus crop production and planting regions.

3. Data collection and processing

Agricultural productivity is highly affected by meteorological parameters such as rainfall, wind speed, solar radiation and air temperature (Hatfield et al., 2011). Hence, the climatic data were collected and analyzed from 16 meteorological stations of meteorological bureau of Mazandaran Province in and around the study area. Because the World Meteorological Organization (WMO) recommends about 30 years for a time series, in this study station data were averaged from 1980 to 2010. Meteorological data layers used included minimum, maximum temperatures (temperature isolines map), relative humidity, rainfall, GDD (growing degree days), sunshine hours, water available (access to spring, well and river) as hydroclimate factors. A questionnaire was set with 14 criteria to recognize a very important effect on citrus production and citrus crop yield. A digital elevation model (DEM) dataset was derived from at 1: 50,000-scale topographic map at a resolution of 80 m. The raster data of latitude, longitude, slope, and aspect were derived from an 80 m × 80 m DEM dataset. These data were collected from various government departments such as; Ramsar agriculture organization for the year 2013, statistical center of Iran for the year 2010 and meteorological data from meteorological stations in and around the study area from climatic atlas of Iran, Iran meteorological organization for the year 2013. Water resources such as, springs, wells and river are collected from Mazandaran and Guilan regional water resources authority for the year 2012. DEM of study area were collected from geological survey of Iran for the year 2011. Citrus orchard requirements and physiology were collected from Ramsar citrus research institute for the year 2012. Roads network were from Mazandaran administration of roads and urban development for the year 2010. A summary of the various data sources used, the type of data they contain and the scale of data aggregation are provided in Table 3. Table 4 represents the chosen meteorological stations.

The main flowchart showing a series of basic steps of LSP is given in Fig. 5. The flowchart describes the procedure using three affective indices including hydro-climate, topography and socio-economic.

4. Results and discussion

The suitability classes are divided into suitable, marginally (moderate) suitable and not suitable. The effectiveness of this method highly depends on the availability of climatic data, topography data and expert knowledge that allow enhancing the site selection assessment. Table 5 gives the weights of criteria that were assigned by expert opinion. These following weights were used in ArcGIS 10.1 to create maps.
Land suitability procedure has expanded by focusing on various critical factors influence on citrus production. The need to produce reliable and robust sustainable citrus planning necessitates to consider a variety of different factors. Hence, an integration of the various factor is needed to support policies and land planning strategies for citrus crop production. Therefore, suitability analysis approach developed based on the relevant positive and negative effect in terms of citrus production to classify each conditioning factor. The list of all the data layers are illustrated in Fig. 6. Our results provide the optimum citrus productivity zones have emerged by overlaying the crucial layers on the basis of hydro-climate, socio-economic and topography factors, which are formed as follows.

For the application of the ANP, all criteria in terms of citrus crop production to achieve sustainable production according to experts' opinion need to be assessed.

Table 3
List of datasets used in the study.

<table>
<thead>
<tr>
<th>Type of data</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Questionnaire</td>
<td>Regarding importance of each criterion to another (based on Saaty's model, 1996)</td>
<td>Experts' opinion</td>
</tr>
<tr>
<td>Land-cover map</td>
<td>Scale at 1: 50,000</td>
<td>2013, Ramsar agriculture organization</td>
</tr>
<tr>
<td>Meteorological statistics</td>
<td>From 16 stations over 30 years</td>
<td>2013, Climatic atlas of Iran, Iran meteorological organization</td>
</tr>
<tr>
<td>Digital elevation model (DEM)</td>
<td>Derived from at 1: 50,000-scale topographic map at 80 m resolution</td>
<td>2011, Geological survey of Iran</td>
</tr>
<tr>
<td>Slope, aspect and elevation</td>
<td>Generated from an 80 m resolution DEM</td>
<td>2014, Geological survey of Iran</td>
</tr>
<tr>
<td>Water resources</td>
<td>Spring, water wells and river</td>
<td>2012, Mazandaran and Guilan regional water authority</td>
</tr>
<tr>
<td>Roads network</td>
<td>Main and secondary roads</td>
<td>2010, Mazandaran administration of roads and urban development</td>
</tr>
<tr>
<td>Population areas</td>
<td>Rural and urban</td>
<td>2010, National censuses of population, Iran</td>
</tr>
</tbody>
</table>

Table 4
Top selection meteorological stations in and around study area.

<table>
<thead>
<tr>
<th>Series no.</th>
<th>Name</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Station class</th>
<th>Elevation (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Toton E Rasht</td>
<td>37.26</td>
<td>49.57</td>
<td>Climatology</td>
<td>–10</td>
</tr>
<tr>
<td>2</td>
<td>Talar sar</td>
<td>36.86</td>
<td>50.73</td>
<td>Climatology</td>
<td>79</td>
</tr>
<tr>
<td>3</td>
<td>Salman shahr</td>
<td>36.7</td>
<td>51.19</td>
<td>Climatology</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>Pilimbra (Naahalestan)</td>
<td>37.59</td>
<td>49.08</td>
<td>Climatology</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>Pasikhan</td>
<td>37.23</td>
<td>49.43</td>
<td>Climatology</td>
<td>45</td>
</tr>
<tr>
<td>6</td>
<td>Noushahr</td>
<td>36.65</td>
<td>51.49</td>
<td>Climatology</td>
<td>21</td>
</tr>
<tr>
<td>7</td>
<td>Niouragh shahid rejaee</td>
<td>36.15</td>
<td>50.3</td>
<td>Climatology</td>
<td>1280</td>
</tr>
<tr>
<td>8</td>
<td>Magsal khalhali</td>
<td>36.13</td>
<td>50.17</td>
<td>Climatology</td>
<td>1200</td>
</tr>
<tr>
<td>9</td>
<td>Khorram abad</td>
<td>36.74</td>
<td>50.61</td>
<td>Climatology</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>Feshalum</td>
<td>37.15</td>
<td>49.37</td>
<td>Climatology</td>
<td>–10</td>
</tr>
<tr>
<td>11</td>
<td>Hir</td>
<td>36.59</td>
<td>50.26</td>
<td>Raininge</td>
<td>1700</td>
</tr>
<tr>
<td>12</td>
<td>Lahidjan</td>
<td>37.18</td>
<td>50</td>
<td>Climatology</td>
<td>86</td>
</tr>
<tr>
<td>13</td>
<td>Baghe-kosar</td>
<td>36.02</td>
<td>50.44</td>
<td>Climatology</td>
<td>1225</td>
</tr>
<tr>
<td>14</td>
<td>Sar limak</td>
<td>36.72</td>
<td>50.57</td>
<td>Raininge</td>
<td>600</td>
</tr>
<tr>
<td>15</td>
<td>Javaherdeh</td>
<td>36.85</td>
<td>50.48</td>
<td>Raininge</td>
<td>2000</td>
</tr>
<tr>
<td>16</td>
<td>Ramsar</td>
<td>36.9</td>
<td>50.66</td>
<td>Synoptic</td>
<td>–21</td>
</tr>
</tbody>
</table>
4.1. Altitude

Typically, yield was negatively correlated with elevation (Mann et al., 2011). Besides, altitude got the highest weight (0.2530) among all criteria in this study (Table 5). With increasing altitude, the potential for frost risk increases in citrus species and cultivars. However, there is no precise report of the highest altitude to citrus cultivation, but an altitude below 700 m has been reported by FAO (http://www.fao.org). The elevation of the study area varies between 20 m and 3620 m above mean sea level (msl) and consists of coastal plains, hills, and mountains. This study reveals that in high altitude, citrus suffer more from critical temperature than in low locations. This layer was classified into 3 classes (see Fig. 6a).

Table 5
The final weights derived from ANP procedure.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Criteria</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Altitude</td>
<td>0.2530</td>
</tr>
<tr>
<td>2</td>
<td>Aspect</td>
<td>0.0276</td>
</tr>
<tr>
<td>3</td>
<td>Distance to roads</td>
<td>0.0145</td>
</tr>
<tr>
<td>4</td>
<td>Growing degree days</td>
<td>0.0069</td>
</tr>
<tr>
<td>5</td>
<td>Maximum temperature</td>
<td>0.1091</td>
</tr>
<tr>
<td>6</td>
<td>Minimum temperature</td>
<td>0.2208</td>
</tr>
<tr>
<td>7</td>
<td>Population areas</td>
<td>0.0440</td>
</tr>
<tr>
<td>8</td>
<td>Rainfall</td>
<td>0.1608</td>
</tr>
<tr>
<td>9</td>
<td>Relative humidity</td>
<td>0.0178</td>
</tr>
<tr>
<td>10</td>
<td>Slope</td>
<td>0.0450</td>
</tr>
<tr>
<td>11</td>
<td>Sunshine hours</td>
<td>0.0122</td>
</tr>
<tr>
<td>12</td>
<td>13</td>
<td>14</td>
</tr>
</tbody>
</table>
Fig. 6. List of all the conditioning factors: (a) altitude, (b) minimum temperature, (c) maximum temperature, (d) rainfall, (e) slope, (f) aspect, (g) relative humidity, (h) GDD, (i) spring, (j) water wells, (k) distance from river, (l) population areas, (m) roads network, and (n) sunshine hours.
Fig. 6 (continued)
4.2. The mean minimum temperature

Temperature is related to latitude and altitude with a vertical declining rate of temperature typically assumed to be −0.6 °C per 100 m (altitude–temperature equation). In the study area, the elevation sharply increases in the southern area. According to expert opinion, minimum temperature is the second critical rank factor in the study area with a weight of 0.2208. Minimum temperature and followed by chilling and frost phenomenon are critical issues for citrus crop production. The minimum temperature required for growing citrus (biological physiological zero or base temperature) is 13 °C (as a threshold value for vegetative and reproductive growth) (Singh et al., 2004). Yield correlated negatively with the number of days with temperature above 30 °C (Plessis, 1982). General conditions for citrus have been worked out, e.g., an average temperature of less than 24 °C is necessary to induce flowering with the minimum growth temperature of 13 °C (Davies and Albrigo, 1994). Chilling damage in citrus fruit may appear in various forms, such as browning of the flavedo (the outer-pigmented layer of the rind) as in oranges. Many citrus cultivars, particularly grapefruit, are sensitive to chilling injury (CI) (Chalutz et al., 1981).

Three classes mean minimum temperature were considered, as shown in Fig. 6b.

4.3. The mean maximum temperature

The maximum mean temperature is also important for determining the suitability of areas for citrus production because high temperatures in the summer season (from June to August) cause water deficiency and stress on citrus trees. The maximum temperature decreases from the Caspian Sea to mountainous areas in the southern part of study area. High temperature (a mean daily temperature greater than 25 °C and maximum temperature of greater than 28 °C) at the time of flower fall has been observed as a limiting factor associated with severe fruitlet drop (Huang et al., 1993). With a weight of 0.1608, maximum temperature is the forth important factor after altitude, minimum temperature and rainfall. Thus, the maximum temperature map of the study area was divided into 3 categories (Fig. 6c).

4.4. Rainfall

Based on the questionnaire and its assigned weight, rainfall is one of the critical factors that have a direct impact on citrus crop yield and development. The lowest amounts of rainfall occur in summer (in particular; in June, July, and August), when, citrus plants need high amounts of water due to high temperature and evapotranspiration. This shortfall in rainfall in the summer month could be overcome by irrigation. Hence, water availability factors including proximity to water wells, distance to rivers and springs were considered important by the experts with a weight of 0.1608. Thus, the regions near the Caspian Sea and in the low land require more irrigation than those in the mountainous southern region. High amount of rainfall, as occurs in October, November and December is also not appropriate for citrus crop production; instead citrus crop production requires uniform rainfall throughout the year. The annual rainfall decreases as altitude increases. For the analysis annual amount of rainfall (190–880 mm) was categorized into three bands (Fig. 6d).

4.5. Slope gradient

While, there is not any basic guideline for a favorable slope for citrus production, according to expert opinion, slope less than 26% are favorable and suitable. Steep slopes cause difficulties during harvest. The slope of the study area was generated from the DEM map, gentle slopes are situated in the northern regions. Slope gradient was divided into 3 classes (Fig. 6e).

4.6. Aspect

Aspect, like the slope gradient was derived from 80 × 80 m cell size resolution of the DEM dataset. Aspect reveals the influence of sunlight radiation on citrus crop production and growth. Around the geomorphological parameters, ‘aspect’ plays a weak role followed by slope angle in terms of citrus crop production in study area. Furthermore, southern aspects receive more direct heat from the sun; drying both the soil and the vegetation. Thereby, south-east, south and east aspect could be more suitable for citrus crop production in comparison with other aspects in the study area. The slope aspect is depicted in Fig. 6f.

4.7. Relative humidity

As a guideline for relative humidity, Lidaniya (2008) proposed that citrus should be produced in areas with high relative humidity conditions. Basically, regions with more than 50% relative humidity are suitable for citrus crop production and growth. High relative humidity has been identified near the Caspian Sea in northern regions of Ramsar while the southern areas near the Alborz Mountains are the least humid. The average relative humidity varies from 20% to 86% in study area. The classification of relative humidity is illustrated in Fig. 6g.

4.8. Growing degree days (GDD)

While, growing degree-days (GDD) is sensitive for the phenology process of citrus trees, based on the experts’ opinions (questionnaire), GDD is not a critical criterion in the study area with a weight of 0.006. As a guideline, citrus trees have a monthly optimum requirement of 180-h total heat unit (degree-days) (Coops et al., 2000). To illustrate the potential (suitable value) in study area, for the GDD values were categorized into three classes (Fig. 6h). The results show that the elevation is highly associated with the growing degree days or heat units in regions within the southern areas and values lower than 154-degree days are unsuitable regions and could be a limitation criterion in study area.

4.9. Sunshine hours

Knowledge of the local solar radiation (W m⁻² per day) of an area is very important for many applications including crop growth models and the design of irrigation systems. Optimum annual sunshine hours for citrus trees are 1000–2700 h per year (Gao et al., 2009). Based on experts’ opinion, the final weight of sunshine duration (SDU) was 0.012. With annual amount of sunshine hours in study area ranging from 1540 to 1772 h, this is not a limiting factor for citrus trees.

4.10. Water accessibility

4.10.1. Spring criterion

Citrus water requirement and its proximity to water resources are very important issues in orchard management. In the late spring and mostly in the summer period, shortage of available water due to high evapotranspiration could be a critical element in the study area. In spite of the fact that springs are most numerous in the study area, most springs have seasonal flow patterns and low discharges in the hot summer months (June and July). Hence, the accessibility to springs is essential regarding citrus crop production. The distribution and density of springs are less in the
northern part (near the Caspian Sea) than in the southern part of study area. A buffer of 1000 m is created as displayed in Fig. 6i.

4.10.2. Distance to water wells criterion

An essential economic issue is the distance of citrus orchards from water wells like springs and river and their availability. The next essential step is the amount of minerals and salt contents and pH; citrus trees are sensitive to excess salts and pH range of 5–8 is preferred. High salinity of water and soil could significantly limit citrus crop yields; however, this did not seem to be a problem in the study area. Based on experts’ opinion, citrus orchards should not be located more than 5000 m away from wells. For this reason, a 5000-m buffer would be placed using the function of GIS software. The various classes of the water wells are illustrated in Fig. 6j.

4.10.3. Distance to river criterion

River flow is another environmental factor that influences citrus crop production in study area. However, based on the questionnaire by experts’ opinion, the final weight of 0.08 was assigned to river flow as well as wells and springs. Based on experts’ opinion a distance of 1000 m is favorable for citrus orchards. In reality, citrus orchards located in proximity to rivers are in less drought stress during hot months i.e. in June and July. Rivers are still an important source of access in some citrus orchard regions. Most dominant citrus orchard areas are located less than 2000 m and are not distant from river flow. Nevertheless, citrus orchards cannot be irrigated by river flow in the hot season (June, July, and August) due to seasonal flow regimes and decrease of volume of water (water scarcity). In the case of the distance from the river map, three buffer classes (from 1000 to 5300 m) were made using the buffer tool in ArcGIS 10.1 software (see Fig. 6k).

4.11. Population areas

Population areas are categorized in the socio-economic cluster to identify the level of its importance to citrus crop production. The weight of 0.04 was assigned to population areas by experts’ opinion. Urban populations are mostly located in the northern part of the study area near the Caspian Sea. As the dimension of green space, orchards have an important role and provide environmental benefits in areas, particularly those areas as densely populated as the northern region of Ramsar. Furthermore, maintenance of orchards such as citrus orchards is very significant as long as they remain within the production system. The buffer of urban population areas is shown in Fig. 6i in study area. In this study, citrus orchards located within or very close to urban areas (less than 2000 m) of Fig. 6i are in a suitable buffer.

4.12. Proximity to roads network

Based on the experts’ opinion a final weight of 0.0145 was assigned to roads network in relation to citrus crop production. Roads network play an essential role in connecting citrus orchards to the market. Proximity of the citrus orchard to roads network have many advantages with regard to decreasing transportation costs and minimizing negative environmental effects. Good access to roads network as infrastructural elements to link the main and local street (first grade street and collector and distributing) are well situated in study area. The presence of road infrastructure and citrus orchards indicate a strong positive relationship. Three classes were categorized with regard to the roads buffer map in study area. The first rank i.e. yellow color from 0 to 1300 m has suitable regions for citrus crop production. In addition, the brown color is suitable for citrus crop production and the pink color and red one are marginally suitable and not suitable for citrus crop production respectively. Fig. 6m shows the buffer of road networks in study area.

In summary, slope and population areas, have approximately the same weight; while, the lowest weights are assigned to distance to road, relative humidity, sunshine hours, aspect and growing degree days. Wind speed, canopy volume, evapotranspiration, and soil characteristics are not considered in this study as field work, literature review and expert opinion, have identified that these factors are not limiting citrus production in this study area. However, it should be noted that in other regions they might be considered important.

After overlying all 14 criteria in ArcGIS software 10.1, the final map shows three productivity zones for the sustainable citrus crop production (Fig. 7).
Analysis of suitability shows that 30% (22296.5 hectares) of the total land in study areas is suitable for citrus crop production, 38% (26910.8 hectares) is moderately suitable, and 32% of study area (23858.9 hectares) is unsuitable (Fig. 7). The suitable regions are located in the northern areas near the Caspian Sea. 

In this paper, we proposed a mean value for suitability zones based on critical variables (except aspect). The results include the mean value performance and the standard deviation (SD) are presented in Table 6.

5. Conclusions

The topography of the study area is hilly and mountainous with a range of altitude of – 20 to 3820 m. This work deals with a comprehensive guideline for the commercial production of citrus with the specific focus on 14 different layers as quality factors. The relative importance of the different criteria, expressed as weights were analyzed based on experts’ opinions.

In this context, climate indicators are the dominant environmental concerns of citrus growth, production, and distribution. Along with altitude and irrigation, temperatures are critical factors in the physical environment of plants. Air temperature exerts a profound influence plant growth and also affects fruit quality characteristic of citrus trees. Furthermore, altitude along with temperature can lead to death under extreme cold or hot conditions. This study also determined the important variables to the prevailing geographic and environmental conditions in order to achieve optimum production. Finding of this study delineates that the current citrus cultivation is lower than the real suitability level. To perceive local biophysical constraints, this assessment is an important step in the development of regional citrus production.

Frost damage is responsible for more economic losses than any other weather related phenomenon in the study area. Consequently, cold stress has one of the most economically important impacts on citrus growth and production. Among the morphological parameters, ‘aspect’ plays a weak role followed by slope angle in terms of citrus crop production in study area.

These results lead to the conclusion that, the most significant factors influencing the sustainability of the citrus crop production, include altitude, minimum temperature, rainfall and maximum temperature respectively. The result further showed that most of the northern area was categorized as highly suitable for crop production.

Our results reinforce the spatial distribution of citrus in Ramsar, where the conditions are more severe in the southern than the northern region. The regions near the Caspian Sea (with temperate zone) were demonstrated as areas for sustainable citrus crop production based on environmental conditions including available water, low altitude, sufficient rainfall events, favorable temperatures and citrus basic requirements. The ANP technique has the potential to be applied to other land evaluation based GIS analysis in the environmental field.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.compag.2015.07.014.


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