AGRO-ECOLOGICAL EVALUATION OF SUSTAINABLE AREA FOR CITRUS CROP PRODUCTION IN RAMSAR DISTRICT, IRAN

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“Dedicated to my wife and my newborn baby”

and

My father and mother

Allah bless them

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ABSTRACT

Citrus growing is regarded as an important cash crop in Ramsar, Iran. Ramsar District has a temperate climate zone, while citrus is a sub-tropical fruit. Few studies on citrus crop in terms of negative environmental factors have been carried out by researchers around the world. This study aims to integrate Geographical Information System (GIS) and Analytical Network Process (ANP) model for determination of citrus suitability zones. This study evaluates the agro-ecological suitability, determine potentials and constraints of the region based on effective criteria using ANP model. ANP model was used to determine suitable, moderate and unsuitable areas based on (i) socio-economic, morphometry and hydro-climate factors using 15 layers based on experts' opinion; (ii) Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite image of the year 2003 with 98.45% overall accuracy, and (iii) developed Multiple Linear Regression (MLR) model for citrus prediction. Thereby, weighted overlay of 15 factors was obtained using GIS. In this study, the citrus orchards map of 2003 and the new map of the citrus areas of 2014 namely Citrus State Development Program (CSDP) of the study area were compared. The results of this study demonstrated: (i) suitable areas (free risk areas) based on negative environmental factors and areas which are susceptible to citrus plantation; (ii) high-risk areas which are unsuitable for citrus plantation, and (iii) the high weights derived by ANP model were assigned to altitude, frost and minimum temperature. The MLR model was successfully developed to predict citrus yield in Ramsar District by 10% error. The MLR model would propose optimum citrus crop production areas. As conclusion, the main outcome of this study could help growers and decision makers to enhance the current citrus management activities for current and future citrus planning.

ABSTRAK

Penanaman sitrus boleh dianggap sebagai tanaman tunai penting di Ramsar, Iran. Daerah Ramsar yang mempunyai zon iklim sederhana, manakala sitrus adalah buah sub-ropika. Beberapa kajian tentang penanaman sitrus dari segi faktor-faktor alam sekitar yang negatif telah dilaksanakan oleh penyelidik di seluruh dunia. Kajian ini bertujuan untuk menilai mengintegrasikan sistem maklumat geografi (GIS) dan model proses analitik jaringan (ANP) untuk penentuan zon-zon sitrus yang sesuai. Kajian ini menilai kesesuaian ekologi pertanian, menentukan potensi dan kekangan kawasan berdasarkan kriteria berkesan dengan menggunakan model ANP. Model ANP telah digunakan untuk menentukan kawasan-kawasan yang sesuai, sederhana dan tidak sesuai berdasarkan (i) sosio-ekonomi, morfometri dan faktor-faktor hidro-iklim menggunakan 15 lapisan berdasarkan pendapat pakar, (ii) Imej satelit Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) bagi tahun 2003 dengan 98.45% ketepatan menyeluruh, dan (iii) membangunkan model regresi linear berbilang (MLR) untuk ramalan sitrus. Dengan itu pemberat lapisan bagi 15 faktor diperolehi dalam GIS. Dalam kajian ini, peta dusun-dusun sitrus 2003 dan peta baru 2014 bagi kawasan-kawasan sitrus yang dinamakan program pembangunan sitrus negeri (CSDP) bagi kawasan kajian telah dibandingkan. Hasil kajian ini menunjukkan: (i) kawasan- kawasan yang sesuai (kawasan bebas risiko) berdasarkan faktor-faktor alam sekitar utama yang negatif dan kawasan-kawasan yang berkemungkinan ada penanaman sitrus, (ii) kawasan-kawasan berisiko tinggi yang tidak sesuai untuk penanaman sitrus, dan (iii) pemberat tinggi yang diperolehi dari model ANP untuk altitud, fros dan suhu minimum. Model MLR dibangunkan dengan jayanya untuk meramal hasil sitrus di Daerah Ramsar dengan selisih 10%. Model MLR mencadangkan kawasan-kawasan pengeluaran tanaman sitrus optimum. Kesimpulannya, hasil utama kajian ini dapat membantu penanam dan pembuat keputusan untuk menambah baik aktiviti-aktiviti pengurusan sitrus untuk perancangan semasa dan yang akan datang.

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LIST OF ABBREVIATIONS

AEZ	-	Agro-Ecological Zones
AHP	-	Analytic Hierarchy Process
ALES	-	Automated Land Evaluation System
ANOVA	-	Analysis of Variance
ANP	-	Analytic Network Process
ASTER	-	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATCOR	-	Atmospheric Correction
B.C.	-	Before Christ
C	-	Carbon
°C	-	Degree Centigrade
CL^{-}	-	Chloride
DEM	-	Digital Elevation Model
Df	-	Degree of Freedom
DSS	-	Decision Support System
DTM	-	Digital Terrain Model
Elev	-	Elevation
ES	-	Ecological Suitability
ESRI	-	Environmental Systems Research Institute
ETM^{+}	-	Enhanced Thematic Mapper Plus
EVI	-	Ecological Vulnerability Index
FAO	-	Food and Agriculture Organization
FLOWA	-	Fuzzy Linguistic Ordered Weighted Averaging
GDD	-	Growing Degree Days
GIS	-	Geographical Information System

GPS	-	Global Positioning System
IFI	-	Integrated Ecology Suitability Index
ILWIS	-	Integrated Land and Water Information System
K	-	Potassium
L.	-	Linnaean
Lat.	-	Latitude
LCA	-	Land Capability for Agriculture
LCC	-	Land Capability Classification
LEIGIS	-	Land Evaluation uses Intelligent GIS
Lon.	-	Longitude
LSIs	-	Land Suitability Indices
MCA	-	Multi Criteria Analysis
MCE	-	Multi Criteria Evaluation
MCDA	-	Multi Criteria Decision Analysis
MCDM	-	Multi Criteria Decision Making
MLR	-	Multiple Linear Regression
mm	-	Millimeter
MOLA	-	Multi Objective Land Allocation
MSL	-	Mean above Sea Level
N	-	Nitrogen
NASA	-	The National Aeronautics and Space Administration
NDVI	-	Normalized Difference Vegetation Index
NDWI	-	Normalized Difference Water Stress Index
NSP	-	Natural and Social Pressure
OWA	-	Ordered Weighting Averaging
P	-	Phosphorus
PH	-	Potential (Power) of Hydrogen
RC	-	Recovery Capacity
RMSE	-	The Root Mean Square of Error
ROI	-	Region of Interest
RS	-	Remote Sensing
SBI	-	Soil Brightness Index

SMCE	-	Spatial Multi Criteria Evaluation
SP.	-	Species
SPP.	-	Species
SPSS	-	Statistical Package for the Social Sciences
SQL	-	Structure Query Language
TEMP	-	Temperature
TM	-	Thematic Mapper
UK	-	United Kingdom
USD	-	United States Dollar
UTM	-	Universal Transverse Mercator
WLC	-	Weighted Linear Combination
WHO	-	World Health Organization

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CHAPTER 1

INTRODUCTION

1.1 Background

Citrus is a genus of flowering perennial plants of the family Rutaceae and sub-family of Aurantioideae. Citrus is one of the world's most important fruit cash crops. It is widely grown in the tropical, subtropical and borderline subtropical areas of the world (CDCGC, 2004). Citrus species grow as large shrubs or small trees about 2-8 meters high, bearing alternate, evergreen leaves, typically aromatic flowers, and large, conspicuously colored (usually orange, orange-red, yellow or green), edible and aromatic fruits. Orange fruits are reddish-green to yellowish-green, rounded, 4-12 cm and the onset of flowering and begin to bear fruit after 3-5 years. Trees' flower and fruits mature differently in different regions around the world. Citrus flowering occurs in April and May in Ramsar district, Iran and some fruits mature from the end of October to February. Figure 1.1 shows an example of two different species of citrus trees.

Citrus is primarily valued for the fruit, which is either eaten alone (sweet orange, tangerine, grapefruit, etc.) as fresh fruit, processed into juice, or added to dishes and beverages (lemon, lime, etc.). All species have traditional medicinal value. Citrus has many other uses including animal fodder and craft and fuel wood.

Figure 1.1 Example of two different species of citrus trees (left panel shows sweet orange and the right panel shows mandarin). (Source: Tree pictures online.com)

Citrus fruits are rich in vitamin C. In brief, vitamin C properties are mentioned below:

i. Degradation of cholesterol, which helps protecting against heart disease;

ii. Reduction of the severity and duration of cold symptoms;

iii. Anticancer properties;

iv. Reduction of the risk of iron deficiency, which causes anemia;

v. Relieve tension, generally strengthen of the body, anti-toxin, anti-seizure medication, etc. (source: www.FAO/WHO.org, 2002).

The importance of citrus horticulture in the world context is shown by its worldwide distribution and its large-scale production. Citrus production (including oranges, grapefruit, tangerines and mandarins, lemons and limes) has experienced continuous growth in the last decades of the twentieth century, reaching a total annual production of more than 120 million tons (FAOSTAT, 2010). Figure 1.2 shows the main production areas in the world.

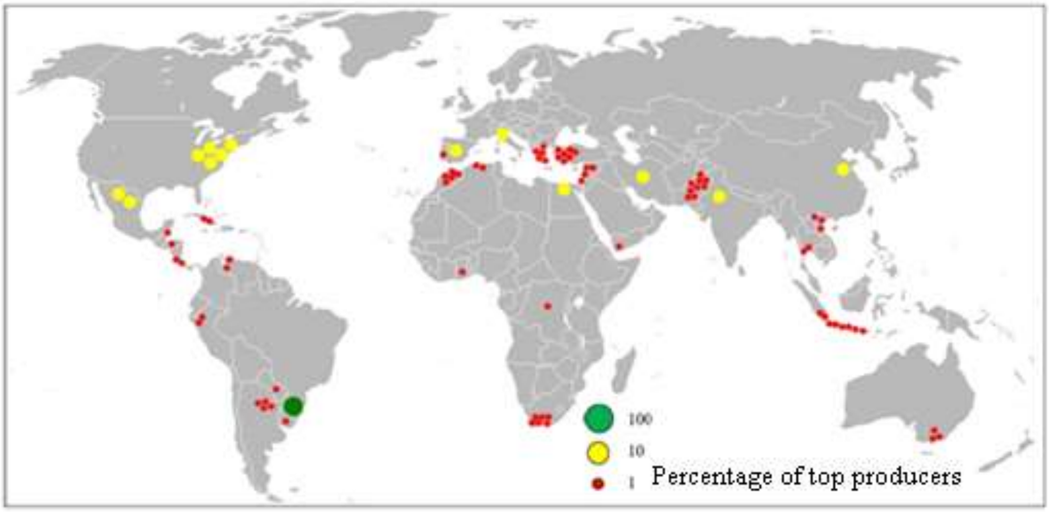

Figure 1.2 Major producers of citrus fruits (FAO, 2007)

Table 1.1 shows top ten major citrus fruit producers. Citrus is grown commercially in more than 140 countries around the world in tropical and sub-tropical climates (approximately 40°N and 40°S of the equator). Due to the citrus adaptation to the tropical and subtropical conditions, these species are easily dispersed around the world.

Table 1.1: Top ten total citrus fruit producers in 2007 (tones) (FAO, 2007)

Country	**Grapefruit**	**Lemon and Limes**	**Oranges**	**Tangerine, etc.**	**Other**	**Total (fruit production)**
Brazil	72,000	1,060,000	18,279,309	1,271,000	-	20,682,309
China	547,000	745,100	2,865,000	14,152,000	1,308,000	19,617,100
U.S.A	1,580,000	722,000	7,357,000	328,000	30,000	10,017,000
Mexico	390,000	1,880,000	4,160,000	355,000	66,000	6,851,000
India	178,000	2,060,000	3,900,000	-	148,000	6,286,000
Spain	35,000	880,000	2,691,400	2,080,700	16,500	5,703,600
Iran	54,000	615,000	2,300,000	702,000	68,000	3,739,000
Italy	7,000	546,584	2,293,466	702,732	30,000	3,579,782
Nigeria	-	-	-	-	3,325,000	3,325,000
Turkey	181,923	706,652	1,472,454	738,786	2,599	3,102,414
World	5,061,023	13,032,388	63,906,064	26,513,986	7,137,084	115,650,545

Iran has always been a major component of citrus production in the world. According to FAO 2007, Iran is ranked seventh in the production of grapefruit, lemon and sweet orange and fifth in the mandarin production in the world. Citrus growing in Iran has a very old history, which goes back as far as 330 BC (Ebrahimi, 2000). Citrus is the most important fruit crop in the world and citrus cultivation in the entire world is 7,600,000 hectares and 290,000 hectares in Iran (FAO, 2007). This study has addressed Ramsar district that is located in Mazandaran province as the biggest producer of citrus with forty-seven percent of the produced citrus crop in Iran. Ramsar district is chosen as the target sample of the study as it is ranked fifth in the Mazandaran province. (Ramsar Agricultural Organization, census bureau, 2010).

There are two major citrus areas in Iran, the Caspian Sea belt and the coast of the Persian Gulf and the Gulf of Oman (southern coastal belt). In the frosty and snowy winter seasons (end of December to February), the damage of citrus fruits by frost is inevitable. In this region, the harvesting time is coincident with late autumn and early winter seasons (end of November to February). In other words, in some years due to frost period and snowy days, all crop yields are destroyed. In reality, the effective environmental parameters and lack of recognition of ecological region's potential were ignored in the area. Citrus production is the main occupation for the growers of this region. Hence, this research attempts to identify negative factors and their effect on citrus production.

The population of the planet is growing dramatically. The farming community is responsible for meeting the increasing demand for food. To ensure a sustainable development and use of resources, planners must know completely and exactly the limitations and capacities of a given area. Knowing the environment extent and its events, conditions and changes are interest. The economic development of each country is largely dependent on its ecological capability derived from its the agricultural production capacity. Land use planning and ecological land capability evaluation are considered the most important tools and factors of sustainable development. There are two concepts that are basic to the system. The first concerns the potential of the land for use in specified ways and the second concern specified management practices (Davidson, 1992).

Land use planning is the process for optimum utilization of human and natural resource potential in the achievement of objectives, growth and balanced society and region. Hence, land suitability analysis is the process of determining the fitness (potentials and constraints) of a given tract of land for a defined use (Steiner *et al*., 2000). In other words, land suitability is the fitness of a certain area of land for a specific use and to determine the suitability level or/and any decision on sustainable land use, which is influenced by these potentials and constraints (Dent and Young, 1981).

The use of Geographical Information System (GIS) on land use suitability analysis has been applied in a wide variety of situations including ecological approaches for defining land suitability/habitat for animal and plant species (Store and Kangas, 2001), suitability of land for agricultural activity (Kalogirou, 2002) and regional planning (Janssen and Reitveld, 1990). GIS technology certainly plays a significant part in a precise agriculture scheme (Washington-Ottombre *et al*., 2010 ; Palaniswami *et al.*, 2011; Walke *et al*., 2012). GIS is used in the field to the scientific analysis of production data at the farm manager's office, and plays an increasing role in the agricultural production throughout the world by helping farmers to increase production, reduce costs, and manage their land more efficiently (ESRI, 2009; 2011). Analytic Network Process (ANP) (Saaty, 2004) and computer based planning tools like GIS can assist in the analysis, integration and interpretation of information (Bojorquez *et al*., 2001; Ayad, 2005).

GIS acts as a powerful tool to analyze both spatial and attribute data and proved its potential to interpret data more accurately (Burrough, 1986; Cowen, 1988; Star and Estes, 1990; Clarke and Lowell 2002; Malczewski, 2004; Longley *et al*., 1999; 2005). It has been widely used in agricultural production, planning and management including citrus growing (Wu *et al.*, 2011). It has successfully indicated areas with the most potential based on the multi-criteria characteristics and also recommended ecological potential and suitable crops to grow all year round. GIS technique is a computer-based technology that describes, stores, manipulates and analyses spatial information. It also presents outputs in the map and tabular for decision making in the planning aspects of agricultural development.

Dent and Young (1981) defined land evaluation as the process of estimating the potential of land for alternative kinds of land use. Conventionally, land capability systems have been used for the following reasons:

i. to contribute to the national inventory of land resources;
ii. to provide a standardized method for assessing land quality as a key component of strategic land use, environment and amenity planning;
iii. as a basis for planning and management, particularly at farm level;

iv. as a component of land evaluation, including the attribution of ecologic and economic value.

Since the late 1980s, multi- criteria analysis (MCA) has been coupled with GIS to enhance multi-criteria evaluation (MCE) methods. Several researcher's have studied multi-criteria decision making (MCDM) in field of agriculture, land use planning, site selection decision and remote sensing (Joerin *et al*., 2001; Gomes and Lins, 2002; Feick and Hall, 2004; Agrell *et al*., 2004; Khoram *et al*., 2005; Perveen *et al*., 2007; Preda *et al*., 2007; Tang *et al*., 2007; Tao *et al*., 2007; Radiarta *et al*., 2008; Ismail, 2009; Abdi *et al*., 2009; Ligmann-Zielinska and Jankowski, 2010; Chen *et al*., 2010a; Etazarini, 2011; Pourebrahim *et al*., 2011; Sahnoun *et al*., 2012).

GIS is playing an active role in spatial modeling (Yaakup *et al*., 2004) spatial problems, such as global and regional changes (Jelineski, 1994) involve a large number spatial decision problems (Malczewski, 2006) and providing alternative scenarios (Yaakup *et al*., 2005). GIS provides facilities to use geographic information to help with decision making and problem solving. GIS, however, is not an automated decision making system, but a tool to query analysis and produce a map in support of the decision making process (Burrough, 1986).

1.2 Problem Statement

Preserving the ecological potential would be realized, whenever land is used according to its capacity and potential. If natural and environmental boundaries were considered in optimum production, the investment would not be wasted.

The geographical environment is dynamic and for having this trait, its changes should be understood and evaluated correctly. In this study, Ramsar district is selected which is located in the west of the Mazandaran province in Iran. The altitude of Ramsar begins at a height of -20 meters near the Caspian Sea to 3600 meters above sea level in the Alborz Mountains. The lowest mean minimum temperature of Ramsar over a-

30 year period is 1.9 ^{o}C, while the lowest recorded temperature was -10 ^{o}C in January (Ramsar Synoptic Station Statistics, 2010).

In addition, there were two frosts in January 2008 and February 2014 as severe as -3 ^{o}C and continued for several days, which was very critical and damaging to citrus (fruits and trees). In fact, the snow destroyed some citrus fruits in this area. The cost of the damage was estimated at around USD 400,000,000 (Sadeghi and Ghanbari, 2008). In reality, citrus trees are semi-tropical plant in origin and cannot tolerate severe frosts and realistically temperatures not falling below -2 °C for successful cultivation (Ghazvini and Moghaddam, 2007). However, the north of Iran (the Caspian Sea belt, particularly), and in some regions of Ramsar county have high potential for production and cultivation of citrus due to favorable ecological potential and climate indicators which make them suitable for citrus planting.

In the literature, few studies were carried out in the field of citrus crop in terms of negative environmental factors. This study is concerned with critical criteria and its impact on citrus as a crucial factor. Many previous researches have been carried out in terms of ecological capability of a given area and used all criteria i.e. climate, soil characteristics and topography criteria, but it was not enough (Khoram *et al*., 2005; Sahnoun *et al*. 2012). Indeed, in the context of environmental assessment based on negative criteria are not considered as the main effective factors on citrus crop production and fruit quality. Few papers deal with integration of GIS-ANP model to evaluate the agro-ecological suitability and spatial distribution of citrus crops. Furthermore, previous researchers ignored the critical factors, and this had the drastic impact leading to the destruction of citrus (fruits and trees) crops in Iran.

Furthermore, a Multiple Linear Regression (MLR) model was developed to validate the results of ANP model regarding citrus production. It should be sataed that, there is no established model done to associate the production of citrus with all those parameters. There is the main gap between suitable regions and citrus planning procedure in Ramsar district, Iran.

In previous studies in overseas (e.g., Ceballos-Silva and López-Blanco, 2003a, b; Kalibatas and Turskis, 2008; Chen *et al*., 2010a; Wu *et al*. 2011; Li *et al*., 2012;

Chung and Kim, 2014; Caubel *et al*., 2015) criteria were considered as climate criteria while the integration of three main factors including socio-economic, hydro-climate and morphometry are neglected. Indeed, this study will try to create limitation layers such as isohyets diagram, minimum and maximum temperature isolines map, relative humidity, population areas, proximity to the river, and road networks could help the user to analyze the suitable regions using analytical network process (ANP) method.

This study focuses on the critical factors that evaluate the agro-ecological suitability and spatial distribution of citrus using GIS and ANP model. This study also attempts to identify problems that significantly influence the production of citrus fruits (crop production). Ultimately, the final map for suitable regions or/and unsuitable regions (high risk for planting) will be created based on the limitation factors for citrus trees and fruits.

The results of this study could surely enhance future citrus crop production planning process of the study area. Accordingly, there is a need to design integrated approaches for agro-ecological suitability, applying techniques such as GIS-ANP to help in bridging the gap between negative factors and citrus crop production planning process. Finally, it needs to design integrated approaches for two main reasons. Firstly, this improves assessment of citrus suitability areas using GIS-based ANP and applying prediction analysis using the developed Multiple Linear Regression (MLR) model.

1.3 **Aim of Study**

The aim of this research is to identify suitable areas for citrus production using the integration of GIS-based ANP model and developed MLR model. The results of this study demonstrate suitable area for citrus production based on environmental factors in Ramsar district, Iran.

1.4 **Objectives of Study**

The objectives of the study are as follows:

i. To identify the hydro-climate, socio-economic and morphometry factors that influence on the citrus production.
ii. To integrate GIS-based Analytical Network Process (ANP) to generate citrus suitability map
iii. To develope a Multiple Linear Regression (MLR) model to predict citrus yield.

1.5 **Scope of Study**

This research focuses on identifying limitation factors in the study area including minimum temperature, maximum temperature, relative humidity, GDD (growing degree-days), sunshine hours, frost, water available (accessibility to spring, water well and river) as hydro-climate factors. Morphometry factors including slope, aspect and altitude. Socio-economic factors including population areas and proximity to roads network (road accessibility). These factors are used in this study to determine the suitable regions in terms of citrus crop production.

Due to the fast growing rate of citrus production in Ramsar district, the government of Iran has identified Ramsar district as a citrus development zone, and accordingly has provided support for the mass production of citrus in the area (Citrus State Development Program (CSDP, 2014). However, it needs an urgent sustainable plan for future citrus production. The main approaches in this study are using Analytic Network Process (ANP) as the multi-criteria evaluation method and using the analytical capabilities of the GIS for citrus production procedure. MLR model was developed to find the coefficients among the fifteen factors regarding citrus yield prediction using SPSS programme.

The ArcGIS 10.2, Super Decision Software version 2.2 and SPSS software version 16.0 have been used for analysis. These approaches can be regarded as a guideline procedure in area exploitation and citrus management. Rapid advances in GIS technology and multi-criteria decision making (MCDM) such as ANP method has created the best opportunity for evaluation of citrus suitability (Ghazvini and Moghaddam, 2007).

This study uses appropriate tools like GIS and the ANP in spatial planning based on hydro-climate, socio-economic, and environmental factors that formed a suitable plan for citrus crop production. There are several reasons that we have chosen ANP model in this study. ANP allows the construction of a model that can incorporate feedbacks and dependencies of factors. This is important for the obvious reason that spatial elements are often associated with each other, such as aspect and land cover for example. ANP technique gives the user the ability to define these dependencies and their direction into a network. In addition, ANP uses the same concept of pair-wise comparison to determine criteria weighting. Consequently, ANP with Super Decision software 2.2 has helped as an effective means of dealing with complex decision making the strategies to be prioritized, optimized and rationalized.

1.6 Significance of Study

Agriculture plays a vital role in the growth and stability of the region's economy. Thus, appropriate areas for plantation and cultivation are important for decision making. Citrus production is regarded as an important cash crop in Ramsar district. This study will develop the economy of Ramsar region and enriches local growers for planting and managing citrus trees and fruits. Therefore, this study could offer an ideal perspective and precision management to growers, planners and decision makers.

This study could provide insight and guidelines for the development of citrus orchards and other potentials fruit crops based on the capability of the zone. There are several benefits and application of this research. The information of crucial environmental factors could help growers and decision makers to refine the current citrus management activities i.e., prevent citrus planting in high-risk areas in the future. There is lack of research that combines these two methods for suitability assessment. Hence, this study will attempt to solve the complex problems and identify the relationships among the criteria and indicators. In contrast, MLR model is applied to estimate citrus yield In Ramsar district, Iran. The MLR analysis is a useful method used to find the relationship between factors (correlation) and predict citrus yield. Therby, MLR was developed to predict citrus yield recommended to other regions as an applicable model. Consequently, insights and guidelines for future citrus production could be provided by using high potential areas based on the impact of environmental factors.

1.7 **Thesis Outline**

Chapter 1 introduces the study, and consists of the background of the study, problem statement, aim and objectives of the study, scope of study, and significance of the study.

Chapter 2 is a review of existing literature and describes the fundamental part of the research which provides appropriate knowledge including the theories and applications employed in this study. This chapter reviews the previous literature related to hydro-climate criteria, morphometry and socio-economic variables as critical factors in terms of citrus production.

Chapter 3 addresses each of the objectives outlined in Chapter 1 by adopting the appropriate research methodology. In Chapter 3, it focuses on ANP as novel method in horticultural crops to solve the problem of citrus production in Ramsar district. MLR model is developed to estimate citrus production. Two essential steps are necessary. First, the critical criteria for citrus crop have to be made known, and second, the planning process to find agro-ecological suitability must be defined. Data collections, data layer, hydro-climate, socio-economic criteria and morphometry are discussed in this chapter. Brief descriptions of methods and criteria using ANP techniques and developed MLR model, to find the significant criteria and relationship between factors and citrus yield are included in this chapter.

Chapter 4 presents the results obtained from the implementation of the methods. The results and relevant analysis are illustrated and elaborated in various forms such as tables and diagrams. In this Chapter, the final equation of MLR is proposed with the mean absolute percentage error.

Chapter 5 delivers the conclusions of the study and makes recommendations for future research.

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