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New Landscape Planning Concepts to Management Strategies for Developing Agricultural Regions

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Abstract

Sustainable land resource management depends on the good assessment and planning of current landscapes. This may be possible with application of multidisciplinary researches, as this study presented a multidisciplinary approach in a spatial database frame work using Geographic Information System. 'Agroecological zones' concept is used to integrating and characterizing homogenous spatial units. This approach combine theme layers include of available water resources, climate, terrain and soil conditions, associated with land use and settlement patterns. Climatic indices layers, including of growing degree days, aridity index, length of growing period and freezing period were created using the correlation between climatic parameter and digital elevation model. Using this approach the Borujen watershed was divided in 28 'agroecological zones' which defined 3 landscapes or agricultural regions. The most important constraints for developing agriculture in landscape I has topographic, climatic and soil constrains, landscape II has topographic and soil constrains and landscape III has the some limitations of soil. Landscape I and II are much less attractive from an agricultural perspective. Landscape III is suitable for agriculture but, the potential for rainfed cropping system is limited by a lack of growing period during which neither temperature nor moisture is limiting to plant production. In general, the case study of the Borujen watershed indicated that this approach can be used for different scales and adaptive to the particular planning.

Keywords: agricultural regions, GIS, landscape planning

Introduction

Iran is characterized by considerable weather variability in landscapes and soil patterns. The combination of these interacting factors leads to different agroecological conditions, which can be suitable for specific land use, or unsuitable for others (Ghaffari, 2008). In spatial terms, agriculture is one of the most important land uses in Iran (Ghaffari, 2008). The management of this land has profound impacts on the quality of the wider environment through, for example, nutrient dynamics, water resources and biological diversity (Araya *et al.*, 2010). Sustainable land resource management depends on the good assessment and planning of current landscapes (Caldiz *et al.*, 2000a; Hengsdijk and Van Ittersum, 2002).

Designing and management a landscape is complex and can neither be solved neither by a single discipline nor by changes only at one particular scale, plot, farm or region. Exploring these alternatives is possible with application of multidisciplinary researches with knowledge and information from different viewpoints and scales (Hengsdijk and Van Ittersum, 2003; Sadras and Calderini, 2009). So, this study present a new multidisciplinary approach for landscape planning in a spatial database frame work using Geographic Information System. In this study, use of spatial concept of "agro-ecological zone" is advanced as a support tool for agricultural planning.

The term agro-ecological zones have several meaning in the literature. For example the Food and Agriculture organizing of the United Nations(FAO), followed later by the International Institute for Applied Systems Analysis (IIASA), has a 25 -year legacy of studies base on concept of agro-ecological zones as spatial entities that delineate areas with different production potential for specific crops (FAO, 1978, 1996, 2002). But differently, FAO and IIASA methods produce crop suitability maps.

In this study, the term of agro-ecological zone is used in a broader sense of integrated and more or less homogenous spatial units in which the particular combinations of available water resources, climate, and terrain and soil conditions create unique environments, associated with land use and settlement patterns. We propose a method that could be used to define agro-ecological zones and to assess landscapes for its agricultural developing potential.

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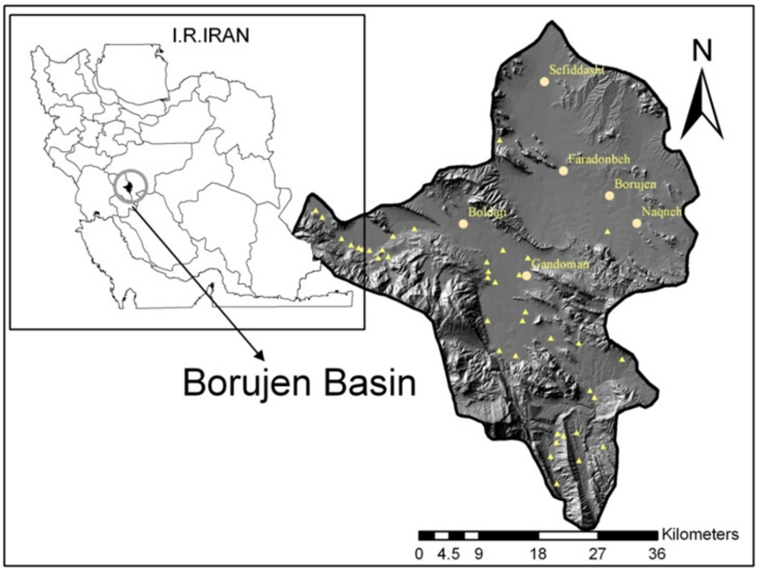

Fig 1. Location of Borujen basin in Chahar Mahaal and Bakhtiari, Iran

The advantage of the proposed method is that it produces synthesis maps of agricultural environments in the Borujen watershed as a case study for cold-semiarid climatic condition of Iran.

Materials and methods

Case study: The Borujen watershed, located in the Chahar Mahaal and Bakhtiari in the western part of Iran (31°29'N, 50°47'E to 32°13'N, 51°26'E; Fig. 1). The climate in the Borujen watershed is semiarid with moderate summer and very cold winter. Average annual rainfall is estimated to be varying from 350 mm in the Borujen station to 600 mm at Imam-Gheis, of which 84% concentrated in the winter and autumn seasons and 15% in the spring. The catchment area is approximately 2114.3 km^2.

Climatic and soil data

Climatic data records 30 years for the period from 1975 to 2005. In nearly all stations vapor pressure, mean wind speed, precipitation, sunshine hours, minimum and maximum air temperatures were available for 18 meteorological stations. In order to produce monthly temperature estimates for each grid cell, topographical and geographical variables of the grid cells containing the 18 observation points were extracted from the DEM derived grids. A correlation matrix was prepared for these variables and the monthly maximum and minimum temperature to select candidate variables of the regression models for predicting temperature at grid cells with no observation stations. A regression procedure using SAS/REG (SAS Institute, 1999) was performed with the selected topographical variables as the independent and temperature data as the dependent variable for each month. Obtained models were applied to the DEM derived grids to produce monthly temperature estimates for each grid cell.

The ETo of the stations in the study area was calculated using Hargreaves's equation and the ETo Caculator (FAO, 2009). The soils were regrouped into 9 soil series or taxonomic units. Each series represents a unique combination of parent material, soil profile development stage, soil depth, drainage and texture (MJA-APERDR, 2000). Aggregated maps at the scale of 1:50,000 give a national overview of the available natural resources of Borujen watershed.

Agroclimatic zoning

These layers were integrated in accordance with the UNESCO classification system for arid zones (DePauw *et al*., 2000; UNESCO, 1979). This system is based on three major criteria: (1) moisture regime, (2) winter type and (3) Summer type (Tab. 1).

Tab. 1. Climatic indices used in UNESCO agroclimatic classification system (UNESCO, 1979)

Moisture regime	(HA) Hyper Arid	(A) Arid	(SA) Semi Arid	(SH) Sub Humid	(H) Humid
(AI) Aridity index	<0.03	0.03-0.2	0.2-0.5	0.5- 0.75	0.75-1
Winter type	(W) Warm	(M)Mild	(C) COOL	(K) Cold	
Mean temp coldest month	>20°C	>10°C	>0°C	≤0°C	
Summer type	Very warm	(W) Warm	(M) Mild	(C) Cool	
Mean temp warmest month	>30°C	>20°C	>10°C	≤10°C	

Moisture and Temperature-limited growing period

The criterion used for the definition of a moisture-limited growing period is the ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET) (Ati *et al*., 2002; Smith, 2000). If this ratio for any particular month is higher than a user-defined threshold (in this study 0.5), that month is part of a growing period; if it is not, that month is not part of the growing period. Similarly, the temperature-limited growing period is calculated with reference to a temperature threshold, below which there was no growing period (user-defined; for this study set to 5°C).

Growing degree days

In order to improve the accuracy GDD values the Tydesly method (Bishnoi, 2010; Tyldesley, 1978) was used in this study.

$HU_i=[(T_{max}+T_{min})/2-T_{base}]\times NumDays_i$ when $[T_{min} > T_{base}]$ Eq. (1)

$HU_i=[1/2(T_{max}-T_{min}) - (1/4(T_{base}-T_{min})] \times NumDays_i$ when $[(T_{max}-T_{base}) > (T_{base}-T_{min})>0]$ Eq. (2)

$HUi=[1/4(Tmax - Tbase)] \times NumDaysi$ when $[0 < (Tmax-Tbase)<(Tbase -Tmin)]$ Eq. (3)

$HU_i= 0$ when $[T_{max} < T_{base}]$ Eq. (4)

and annual *GDD* or $AHU=\sum_{i=1}^{12} HU_i$ Eq.(5)

where HU_i: heat units during month i, NumDays: number of days in month i, T_{base}: temperature below which no accumulation is done (in this study: 5°C), T_{min}: monthly minimum temperature, T_{max}: monthly maximum temperature. Wheat heat units' requirement was calculated from planting date to harvesting time.

Landforms

The map of Landforms has been prepared on the basis of SRTM DEM, using criteria elevation, slope and aspect. Three elevation classes were recognized (2000-2400, 2400-2800 and 2800-3200 m). Four slope classes were differentiated (0-5%, 5-12%, 13-30% and >30%), and three aspect classes (in differential, northern aspect and southern aspect) using relevant to surface function in ArcGIS. The aspect is north if compass bearing was in range 0-67.5 and 292.5-360 and south if the compass bearing was in the range 112.5 and 247.5. Any other compass bearing or the class Flat fell in the category undifferentiated aspect (DePauw *et al*., 2008). SRTM DEM (20 meter grid cell size) was used to derive landforms through a simplified 3-class system, based on the concept of 'relief intensity'. 'Relief intensity' is derived from the maximum elevation difference between two neighboring pixels and classified as: 1: Plains: relief intensity 0-50m, 2: Hills: relief intensity 50-300 m and 3: Mountains: relief intensity >300 m (DePauw *et al*., 2008).

Integration of thematic layers

Once the component layers have been established, AEZs are generated through overlaying in a GIS procedure according to Fig. 2 that retains all characteristics and attributes of the component themes. Given the range of

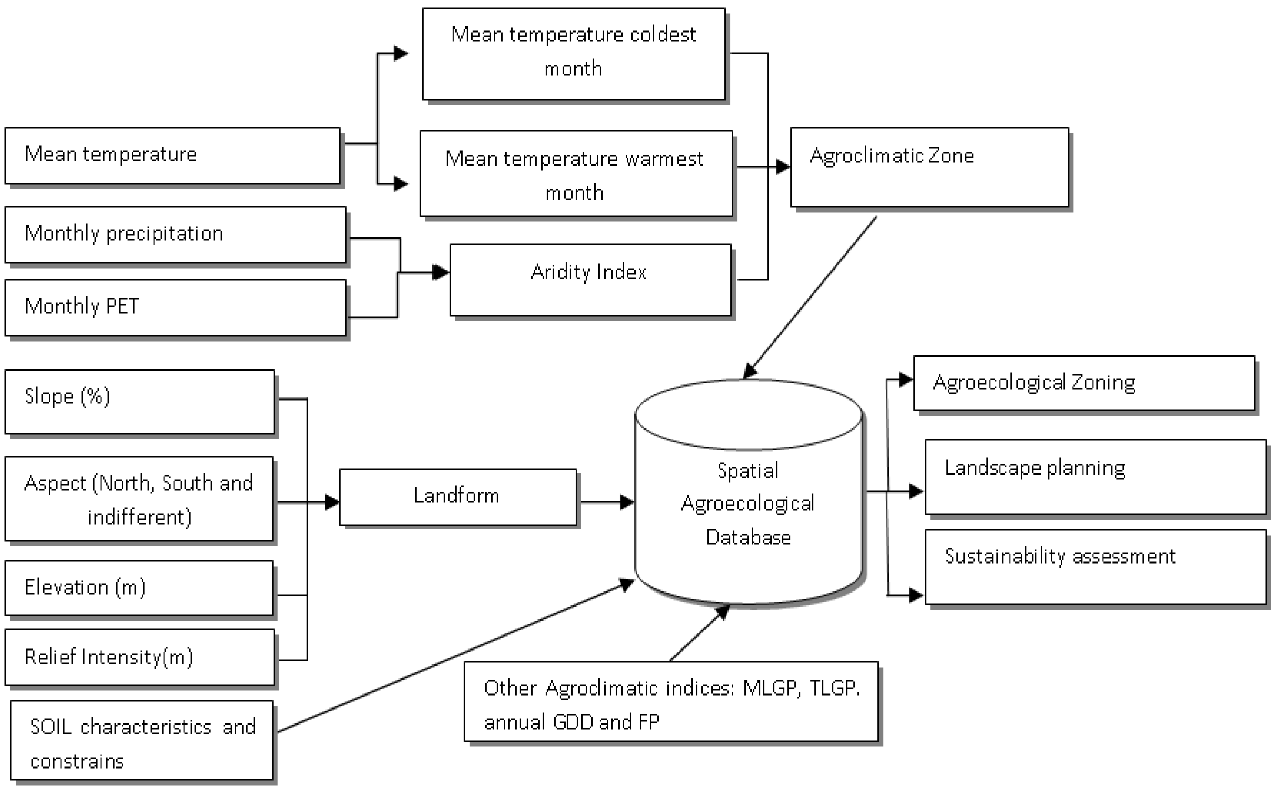

Fig. 2. Framework and information flow for create spatial database and agroecological zoning

combinations that are possible by the overlaying process, it is necessary to represent AEZs through a unique ID.

A simple coding system was developed by concatenating numerical codes for each theme that is used for identifying the AEZs. In our assumption that agricultural environments can be reasonably represented by the themes climate, land use/land cover, landforms and soils, a generalized coding system would have the format 'CULS', in which: C: Climate Code, U: Land Use/Cover Code, L: Landform Code and S: Soil Management Domain Code. By overlaying the 4 themes the AEZ codes are generated using the appropriate multipliers and summation method. Fig. 3 shows spatial information outputs which achieved from Agroecological zoning process.

Result and discussion

This methodology was divided Borujen watershed to 4 agroclimatic zones. 64% of this region have 'semi arid climate with cold winter and very warm summer (SA-C-VW), '12.3% with cold winter and warm summer (SA-C-W)' and 20.8% with very cold winter and warm summer (SA-K-W), 2.3% semi arid climate, with cold winter and moderate summer (SA-K-M). A total of 28 AEZs and were identified using the methodology described in this study (Fig. 3-map 6). The spatial distribution of AEZs was presented in Fig. 3-map 7 and their agro ecological characterization was showed in Tab. 3. The dominant ecological units are 20 (1-4-5-11), 22 (2-4-7-11) and 26 (4-4-11-11)

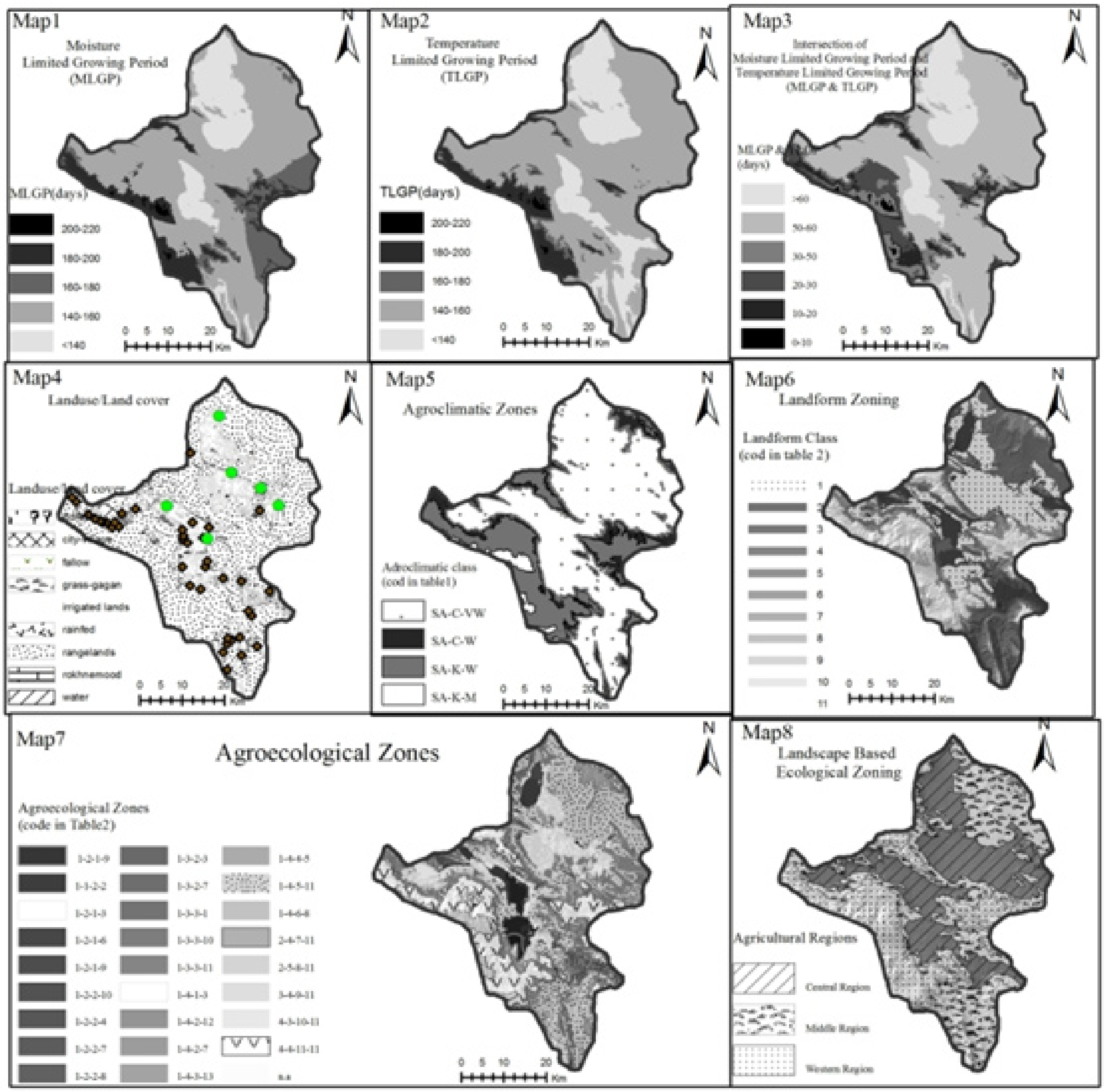

Fig. 3. Important spatial information outputs, achieved from Agroecological zoning process

Tab. 2. Charactarization of Agroecological Zones in the Borujen watershed

Soil constrains [3]	Landform (map6)					Landuse (map 4)	Agroclimatic class [2] (map 5)	Area (%)	AEZ Cod(C-U-L-S) [1]	Row
	Relief intensity	Dominant slope(%)	Aspect of slope	Mean elevation(m)	Landform cod					
STП	0-50m	0-5	Northern	2000-2400	1	Irrigated agric	SA-C-VW	0.58	1-2-1-9	1
SП	0-50m	0-5	Southern	2000-2400	2	Irrigated agric	SA-C-VW	1.53	1-2-2-10	2
VW	0-50m	0-5	Southern	2000-2400	2	Irrigated agric	SA-C-VW	1.99	1-2-2-2	3
STП	0-50m	0-5	Northern	2000-2400	1	Irrigated agric	SA-C-VW	9.64	1-2-1-3	4
SW+ШW+VWШ	0-50m	0-5	Southern	2000-2400	2	Irrigated agric	SA-C-VW	1.06	1-2-2-4	5
STП	0-50m	0-5	Northern	2000-2400	1	Irrigated agric	SA-C-VW	0.31	1-2-1-6	6
T+IV TШ	0-50m	0-5	Southern	2000-2400	2	Irrigated agric	SA-C-VW	0.457	1-2-2-7	7
I	0-50m	0-5	Southern	2000-2400	2	Irrigated agric	SA-C-VW	0.535	1-2-2-8	8
IV S	0-50m	5-12	Southern	2000-2400	3	Irrigated agric	SA-C-VW	0.285	1-3-3-1	9
SП	0-50m	5-12	Southern	2000-2400	3	Rainfed agric	SA-C-VW	0.139	1-3-3-10	10
STП	0-50m	0-5	Southern	2000-2400	2	Rainfed agric	SA-C-VW	0.852	1-3-2-3	11
T+IV TШ	0-50m	0-5	Southern	2000-2400	2	Rainfed agric	SA-C-VW	0.772	1-3-2-7	12
R	0-50m	5-12	Southern	2000-2400	3	Rainfed agric	SA-C-VW	0.055	1-3-3-11	13
VI /M	0-50m	0-5	Southern	2000-2400	2	Rangeland	SA-C-VW	0.167	1-4-2-11	14
IV S	>300m	5-12	Indifferent	>2800	2	Rangeland	SA-C-VW	1.05	1-4-2-12	15
SП	0-50m	5-12	Southern	2000-2400	3	Rangeland	SA-C-VW	0.175	1-4-3-13	16
STП	0-50m	0-5	Northern	2000-2400	1	Rangeland	SA-C-VW	0.10.3	1-4-1-3	17
IV ST	0-50m	5-12	Northern	2000-2400	4	Rangeland	SA-C-VW	0.131	1-4-4-5	18
T_IV TШ	0-50m	0-5	Southern	2000-2400	2	Rangeland	SA-C-VW	1.067	1-4-2-7	19
IV S+ IV ST+ VW	>300m	12-30	Southern	2000-2400	5	Rangeland	SA-C-VW	28.69	1-4-5-11	20
I	>300m	0-5	Indifferent	2000-2400	6	Rangeland	SA-C-VW	0.179	1-4-6-8	21
R	>300m	>30	Indifferent	2400-2800	7	Rangeland	SA-C-W	12.16	2-4-7-11	22
R	>300m	12-30	Northern	2400-2800	8	Forest	SA-C-W	0.028	2-5-8-11	23
R	>300m	>30	Northern	>2800	9	Rangeland	SA-K-W	2.31	3-4-9-11	24
R	>300m	0-5	Southern	2400-2800	10	Rainfed agric	SA-K-M	0.35	4-3-10-11	25
R	>300m	>30	Northern	2400-2800	11	Rangeland	SA-K-M	20.42	4-4-11-11	26
Cities and Villages							-	1.17	C-na	27
Water, wet lands, rock outcrop							-	2	na,	28

1-A generalized coding system would have the format 'CULS', in which: C: Climate Code, U: Land Use/Cover Code, L: Landform Code and S: Soil Management Domain Code; 2- see Tab. 1; 3-Class I: well arable land with no limiting for irrigation, class II: arable land with low limiting for Irrigation, classIII: arable land with medium limiting for Irrigation, class IV: arable land with high limiting for Irrigation, class V: unstudied land with high limiting for Irrigation, classVI:unarable lands; S: subclass defining soil constrains(texture, permeability, depth, gravel, etc, T: .topography constrains, W: drainage constrains, R: Hills and outcrop rocks; na: not applicable for agriculture

that covered 28.7%, 12.1% and 20.4% of total study area, respectively. The most important constrains of landform in these unites is high slope and relief intensity. These units have also soil constrains including low soil depth, poor drainage, lime hardpan, rock outcrop and low organic carbon (Tab. 2). Thus unites of 20, 22 and 26 are not suitable for agricultural use; any tillage operation in these area will cause soil erosion and land degradation. The ecological unites of 4 (1-2-1-3) and 17 (1-4-1-3) covered 9.6% and 10.3% of total study area respectively.

There is low limitation for landform unites but some constrains of soil including soil texture, low soil organic matter and high lime content have been limited agricultural production. The most landuse in the unit 4 is currently irrigated agriculture and in the unit of 17 is rangeland that has potential to convert in agricultural use (Tab. 2). Agricultural limitation for other zones is presented in Tab. 2.

The diversity of topography, local climatic condition, landuse in the Borujen watershed has created different agricultural regions. An agricultural region defined as 'holistic spatial entity with its own biophysical and socioeconomic personality' (DePauw *et al*., 2008; Kiryushin, 2007). The number of agroecological parameters that should be taken into assessment of these areas depends on the level of agricultural intensification. Agroecological groups of lands are separated with respect to the major limiting agroecological factors (automorphic leveled land plots, erosion lands, waterlogged lands, salt-affected lands, solonetzic lands, etc. In this study three agricultural regions was recognized regarding to agroecological parameters, which presented in Tab. 3. These agricultural regions are: (a) west agriculture region, (b) middle agricultural region and (c) center agricultural region. In the fallow were described characteristics of these agricultural landscapes (spatial distribution of agro-landscape is shown in Fig. 3 -map 8).

(a) Landscape I or West agriculture region: this region, covering about 485.5 km^2, is characterized with semi arid climate, very cold winter and cool summer (SA-K-W), degree day of 2790 GDD, high intensity of relief, hilly area and High Mountain (2800-3800 m) (annex 1-map 8). Freezing period of this landscape starts in late of October and continuous to May (Tab. 4). The length of moisture limiting growing period (MLGP) and temperature limiting growing period (TLGP) are 182 days and 148 days respectively while the length of temperature and moisture limiting growing period is 20 days (the intersection of TLGP and MLGP). In the other hand the optimum duration, which neither moisture nor temperature is limiting for the crop growing, is 20 days. As the results show the most important factors that have limited agricultural development in the west agricultural region are climatic and landform constrains (Tab. 4).

(b) Landscape II or Middle agricultural region: this region, covering about 911.3 km^2, is characterized with semi arid climate, cold winter and warm summer and its topographic aspects exception its average elevation (2400-2800 m) is same as west agricultural region. Mean annual of maximum temperature in this landscape is 17.5°C and the mean annual of minimum temperature is 2.2°C. In view of the lower elevation the temperature regime is less restricted by cold conditions as in northern region. The annual mean growing degree day in this agricultural region is 35.84% more than west agricultural region. The growing period during which neither temperature nor moisture is limiting to plant production is also more than western region.The analysis of agroecological characteristics in eastern agricultural region show that this region have no climatically constrains for irrigated agricultural production but its landform properties have limited severely. Owning to topographical limitation (slope=5-30%) lands in this region not suitable for agriculture. Steep slopes in the mountainous areas present problems similar to those described already for the steep soils of western agricultural region. The risk of soil erosion continues to be high, and maintenance of soil fertility through an effective integration of traditional crop and livestock production systems is necessary.

(c) Landscape III or Center agricultural region: this region which covers about 713.3 km^2 in Borujen watershed is characterized with semi arid, cold winter and very warm summer, most part of this landscape is flat to almost flat (slop=0-5%) and located between 2000-2400m(map 6).

In the central agricultural region mean of annual minimum temperature is 3°C and its mean of annual maximum temperature is 18.5°. Agroclimatic indices of this landscape are almost same as the eastern agricultural region. In central region temperature 'stack' exceeds 3900 GDD per year and freezing period declining to 90 days that starts at December and continues to end of February. The length of moisture limiting growing period (MLGP) and temperature limiting growing period (TLGP) are 140 and 255 days, respectively. The growing period during which neither temperature nor moisture is limiting to crop production is more than other landscapes. The growing season in the Borujen watershed extends between December and March, when minimum annual temperature coincides with the rainy season. The most important limitation in this region is some soil constraints.

Landscape planning in this study was based on 'agro-ecological zones' (AEZs). Using this concept the Borujen watershed was divided in 28 'agro-ecological zones' and 3 landscapes or agricultural regions. Agro-ecological attributes which essential for developing agriculture was assessed and resultant maps showed landscape I or the west agricultural region has topographic, climatic and soil constrains, landscape II or the middle agricultural region has topographic and soil constrains and landscape III or the central agricultural regions has the some limitations of soil. Landscape I and II are much less attractive from an agricultural perspective. Landscape III is suitable for agriculture but the potential for rainfed cropping system is limited by a lack enough growing period during which neither temperature nor moisture is limiting to plant production.

Tab. 3. Identified agroecological regions. (Spatial distribution of regions was presented in map 8

Agoecological Region	Agroclimatic lasification	Elevation (m)	Dominant slop(%)	Onset Freezing period	End of Freezing period	Length of freezing period	TLGP (days)	MLGP (days)	Intersection of TLGP and MLGP (days)	GDD	Ratio of region to all area
(West)	SA-K-W	2800-3800	>30%	1 November	10 April	160	148	182	<60	2790	23.15
(Middle)	SA-C-W	2400-2800	5-30%	10 December	1 April	110	227	168	50-80	3865	43.1
(Central)	SA-C-VW	<2000	0-5%	20 December	10 Mars	80	255	140	80-100	3930	33.74

Agro ecological zones have been use in different region or countries for a variety of agricultural purpose (DePauw *et al*., 2008). They may include identification of agricultural production zones (Caldiz *et al*., 2002b), cropping system analyzing (Araya *et al*., 2010; Caldiz *et al*., 2002a; Geerts *et al*., 2006; Smith, 2000), positioning of research stations (DePauw *et al*., 2008) targeting of new technology and cultivars (Mkhabela *et al*., 2005) and crop suitability planning (Mandal *et al*., 2002; Sharma *et al*., 2010; Wu *et al*., 2006). Virtually all systems for defining AEZs in different countries are 'ad-hoc' and stand alone based on different classification methods.

Conclusions

In this study it has been presented a new agro-landscape zoning system, based on the correlations between elevation and temperature combined with the reference evapotranspiration, rainfall, temperature, landform, landuse and soil constrains. LGP concept was used as powerful index in order to define temperature limiting growing period and moisture limiting growing period. In general, the case study of the Borujen watershed indicated that the approach which defined AEZs in this study can be used for different scales, ranging from the global to the sub national, subject to use of appropriate and well matching datasets, and adaptive to the particular planning needs.

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