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USING MicroLEIS DSS TO ASSESS THE IMPACT OF CLIMATE CHANGE ON LAND CAPABILITY IN THE MIANDOAB PLAIN, IRAN

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Abstract: Climate change is the most important challenge in the world because it impacts the environment. This study assessed the effects of climate change on bio-climatic constraints and land capability classes in a semi-arid region, the Miandoab Plain (West Azerbaijan Province, Iran), using Terraza and Cervatana models. After assessing for bioclimatic deficiency using the Terraza model, the Cervatana model was applied to separate the best agricultural lands from marginal ones. Three climatic eras were selected: 1) present, 2) short-term future (after 35 years), and 3) long-term future (after 65 years). Morphological and analytical data were collected from 35 representative soil profiles in the Miandoab Plain. After assessing the bioclimatic deficiency conditions, the land capability for wheat, alfalfa, and sugar beets was then evaluated. Results revealed that the study area is not capable of growing sugar beets and alfalfa, but it is capable of growing wheat under rainfed conditions. The Terraza model results showed a positive response to climate change but with a reduction in yield for wheat and sugar beets in the future. In the next step, and based on the results from the Cervatana model, approximately 89.9% of the study area was classified as moderately suitable land (S3b and S3lb), while 10.1% was classified as unsuitable land (Nl) due to soil salinity and bioclimatic deficiency limitations. The results were integrated with a geographic information system (GIS) to manipulate and prepare georeferenced thematic maps.

Keywords: Bioclimatic deficiency, Cervatana model, Climate change, Land capability, Terraza model

1. INTRODUCTION

Climate change and its consequences have been widely discussed over the past several decades. As part of the global challenge to address climate change, climate diversity has had a serious an impact on agriculture. Climate change has been previously studied in some countries, such as Romania, and further attention has been paid to its impact on air temperature, precipitation, wind, cloud cover, humidity, and snow (Cheval et al., 2014). As a country with an arid to semi-arid climate, Iran is mostly characterized by low rainfall and high potential evapotranspiration. The average annual precipitation in Iran is estimated to be around 250 mm, occurring mostly from October to March. Iran's climate and aridity have been explored based on temperature and precipitation data modeled from 1961 to 2050 (Eslamian et al., 2009). That model also revealed that southeastern Europe is experiencing an ongoing process of warming, and the amount of precipitation has increased in the northern part of the domain and decreased in the southern part (Cheval et al., 2017).

Agricultural areas are highly vulnerable to climate change. Climate change exacerbates the challenges faced by the agriculture sector, negatively affecting both crop and livestock systems in most regions. Climate change also contributes to resource problems beyond food security, such as water scarcity, pollution, and soil degradation (Ignaciuk & D'Croz, 2014). Lefroy et al. (2010) evaluated the potential impacts of climate change on land use in the Lao Peoples Democratic Republic (PDR). That study reported that the change in bioclimatic suitability for the predicted 2050 climate was positive for some crops (sugarcane, cassava, rubber, banana, teak, and paddy rice), negative for some crops (maize, soybean, chili, common bean, sweet corn, Arabica coffee, Jatropha, and eucalyptus), no change for some crops (peanuts and upland rice), and positive and negative in different parts of the country for Robusta coffee. The Intergovernmental Panel on Climate Change (IPCC, 2014) reported that there will be a significant increase in annual minimum and maximum temperatures throughout the west Asia for all four seasons. The historical data indicates that wheat production will be sharply reduced due to a reduction in the amount of rainfall as well as the occurrence of drought.

Climate change alters rainfall, runoff, and evaporation of soil moisture storage. Increased evaporation from the soil accelerates plant transpiration and water stresses. Hence, future scenarios of the impact of climate change parameters emphasize implementation of irrigation projects and strategies that have been adapted to address climate change. In such circumstances, climate-induced drought or wetness may have positive or negative effects on agricultural production and food security in Iran (Amiri & Eslamian, 2010). Assessing crop evapotranspiration under climate change in the Pannaonian Basin using a 1961–2050 model revealed that crop evapotranspiration varied from 105–1087 mm (Nistor et al., 2017). Thus, climate change presents a significant challenge to the environment and affects many aspects of agriculture.

Over the last decade, increasing application of information technology to land evaluation procedures has led to the development of land evaluation information systems (De la Rosa et al., 2004). The MicroLEIS decision support system (DSS) consists of 12 models within five packages to evaluate suitability and vulnerability. The models have successfully classified the investigated area into optimal and marginal agricultural lands. The MicroLEIS DSS has also previously been used in West Azerbaijan Province in Iran (Shahbazi & Jafarzadeh, 2010). In previous studies, many researchers have accepted the efficiency of MicroLEIS DSS evaluation (De la Rosa et al., 2009; Anaya-Romero et al., 2015). In some cases, researchers have modified the programming codes to create their own versions of models in order to apply those to specific geographic conditions (Bojorquez, 1999).

MicroLEIS DSS has been applied to evaluate land use planning in the Ahar area of East Azerbaijan. According to the results, 45% of the total land area was classified as having a good capability for agricultural use and, in order to minimize land degradation, almost 12% of the area should be reclaimed by suitable shrub species instead of being dedicated to agriculture (Shahbazi et al., 2008). Shahbazi & De la Rosa (2010) used the Terraza model to investigate the impact of climate change on the potentialities and vulnerabilities of agricultural lands. Abd-Elmabod et al., (2010) employed MicroLEIS DSS to evaluate the impact of climate change on land suitability in Andalusia, Spain. The results showed that climate change is likely to cause severe water stress in cultivated land. Accordingly, the following low to high suitability trend for crops in response to climate change was proposed: cotton, maize, sunflower, potato, soybean, and wheat.

In the present study, the Terraza and Cervatana models within the Protection and Ecosystem MicroLEIS DSS package were applied to evaluate the agricultural land in the Miandoab Plain in the northwestern region of Iran. The study also estimated the reduction in yield due to the impact of climate change. To evaluate the current climate situation and climate change scenarios, three periods were considered: the present (2006–2015) and two future scenarios: a short-term era (the 2050s) and long-term eras (the 2080s). Therefore, the study aimed to evaluate the impact of climate change on land capability using a DSS model, and the results were integrated into a geographic information system (GIS) to create maps.

2. MATERIALS AND METHODS

2.1. Study area description

The study area, with an extension of about 25,000 ha, is located in the northwestern region of Iran in West Azerbaijan Province (Fig.1).

The geographic coordinates of the study area are 45° 01' 05" to 46° 05' 48" east longitude and 36° 55' 58" to 37° 05' 40" north latitudes. The slope (about 1% to 2%) also varies from the southeast to the northwest. The elevation of the study area ranges between 1280 m and 1290 m; that information was extracted from a Digital Elevation Model (DEM). According to the Miandoab synoptic station report, annual rainfall is 272.3 mm with annual maximum and minimum mean temperatures of 19.9ºC and 12.8ºC, respectively, for the last decade (2006–2015). A short rainy season occurs from June to September, while the main rainy season occurs from October to May. However, it has been recently observed that the rainfall distribution is very unpredictable.

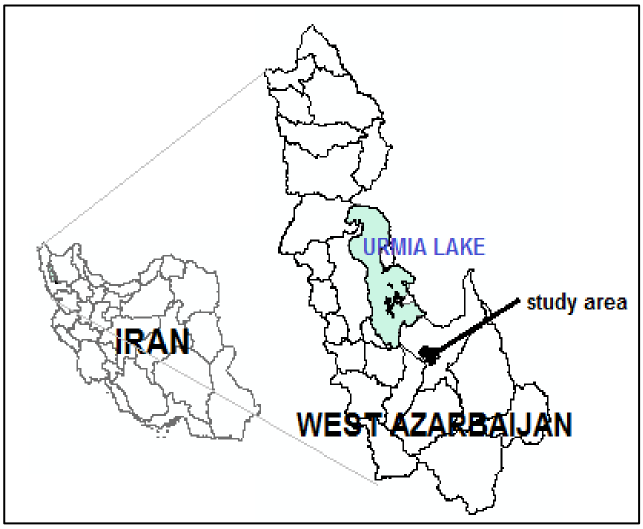

Figure 1. Location of the study area.

2.2. Climate data

Agro-climatic data, temperature and precipitation, were obtained from the Miandoab synoptic station, which provides monthly average values of climate variables: the mean, maximum, and minimum temperature, rainfall, and the number of days of rain and humidity. The data were collected during a consecutive period of 50 years (1966–2005) and (2006–2015), representing the past and current climate scenarios. The future climate is represented under an A1M scenario for the short-term future (the 2050s) and the long-term future (the 2080s). These scenarios were calculated using climate change variation values from IPCC (2007).

2.2.1. Climate data warehousing

Climate change scenarios can be used to identify future changes in land suitability (Brown et al., 2008). Thus, climate data can be entered into the CDBm database within the Information and Knowledge package (De la Rosa et al., 1986). In the present study, the CDBm climate database was used to store the maximum, minimum, and mean temperatures as well as the total precipitation for 12 months as the climate input data. This software can be used to calculate the required agro-meteorological parameters. For example, the Thornthwaite method (Thornthwaite, 1948) was employed to calculate potential evapotranspiration based on temperature and the latitude correction factor (by day). The summarized output data include the humidity index (HUi), the aridity index (ARi), the growing season (GS), the modified Fournier index (MFi), and the Arkley index (AKi). HUi is employed to estimate the overall available water for plant growth, and it is commonly used to predict the artificial drainage needs of a zone. ARi is used to estimate the general aridity of a region's climate as an annual index. GS indicates the period with sufficient moisture and no thermal restrictions for crop production. MFi is frequently used to estimate the erosivity of rainfall (R factor) during the soil erosion process, and ARi is used to estimate the effects of climate on the degree of soil leaching (Arkley, 1963). The results of the CDBm program calculations are shown in Table 1.

2.2.2. Climate change scenarios

Following the IPCC report, the mean temperature will increase by 5.1 ºC, 5.6 ºC, 6.3 ºC, and 5.7 ºC in winter, spring, summer, and autumn, respectively, for the future scenario (the 2080s) in the study area The total precipitation will decrease by 11% and 25% in winter and spring and increase by 32% and 52% in summer and autumn (Shahbazi et al., 2009). In addition, predictions for the study area using the A1M method (the highest future emission trajectory) indicate that the mean temperature will increase by 3.1 ºC, 3.2 ºC, 3.7 ºC, and 3.6ºC in winter, spring, summer, and autumn, respectively, for the short-term future scenario (the 2050s). The total precipitation will decrease by 3% and 8% in winter and spring and increase 13% and 27% in summer and autumn, respectively (Table 2).

2.3. Land and soil characteristics

The river alluvial plain is the main physiographic unit identified in the study area. Moreover, a few low-lying and topical hills (20 m to 35 m) with a very low extent-area were seen in some parts of the study area. According to the Soil Taxonomy Classification System (USDA, 2014) the dominant soil orders are aridisols, alfisols, and entisols. In addition, there are seven soil sub-groups in the study area (Table 3). The soil map of the study area, based on the subgroup category, is shown in Figure 2.

2.4. Model usage

The Terraza and Cervatana models contained in the Protection and Ecosystem package of the MicroLEIS DSS were used to estimate the yield decline in response to climate change in the study area. The CDBm program was also used to store the data and calculate some of the parameters needed to run both of the models.

Table 1. Miandoab synoptic station data calculated by CDBm (current scenario)

Months	**Tm**	**Tmax**	**Tmin**	**P**	**Pmax**	**ET°**	**Hui**	**Ari**	**GS**	**Mfi**	**Aki**
January	0.1	4.9	-4.7	24	9.1	0	---	---	---	---	---
February	3.3	8.7	-2.2	8.7	15.3	5.8	---	---	---	---	---
March	7.7	13.9	1.5	30.9	12.4	24	---	---	---	---	---
April	11.3	17.1	5.5	46.3	14.8	44.4	---	---	---	---	---
May	16.8	24.5	9.1	20.5	9.3	86.4	---	---	---	---	---
June	21.7	30.5	12.9	4.5	3.2	125	---	---	---	---	---
July	25	33.7	16.2	1.5	1.2	155	---	---	---	---	---
August	24.8	34.1	15.5	0.9	0.8	144	---	---	---	---	---
September	20.5	29.9	11	7.4	4.3	96.6	---	---	---	---	---
October	13.9	21.8	5.9	46.3	17.1	52	---	---	---	---	---
November	7.1	13	1.1	54.5	31.1	17.5	---	---	---	---	---
December	1.7	6.9	-3.5	26.9	10.1	2.2	---	---	---	---	---
Annual	12.8	19.9	5.7	272	129	753	0.36	6	9	37	97.4

Tm: mean temperature, Tmax: maximum temperature, Tmin: minimum temperature, P: precipitation, Pmax: maximum precipitation per day, ET^o (T): evapotranspiration calculated by the Thornthwaite method, HUi: humidity index, ARi: aridity index, GS: growing season, MFi: modified Fournier index, AKi: Arkley index.

Table 2. Predicted mean annual temperature and precipitation (IPCC, 2007)

Future scenarios (A1M method)	**Annual temperature, ˚C**				**Annual precipitation, %**			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
(2050s)	+3.1	+3.2	+3.7	+3.6	-3	-8	+13	+27
(2080s)	+5.1	+5.6	+6.3	+5.7	-11	-25	+32	+52

Table 3. Major soil subgroups in the study area

Soil subgroup	No. of Profiles	Area extension	
		(ha)	(%)
Xerertic Haplocambids	6, 13, 16, 19, 24, 26, 31, 32, 35	8317.7	35.87
Typic Haploxeralfs	3, 4, 17, 18, 25, 28, 30, 33, 34	7513.2	32.4
Xeric Torrifluvents	7, 12, 14	1134.06	4.89
Xeric Torriorthents	1, 5, 15, 22, 23, 27, 29	3728.12	16.08
Natric Haploxeralfs	9, 11, 20, 21	1579.1	6.81
Typic Natraqualfs	2	79.47	0.34
Typic Aquisalids	8, 10	834.72	3.6

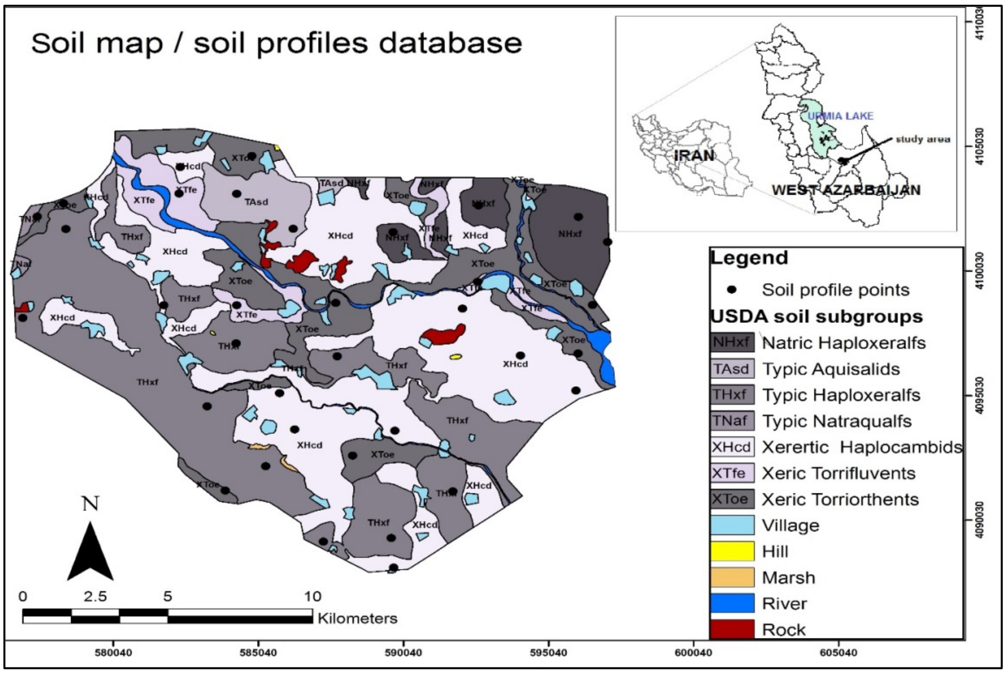

Figure 2. USDA soil subgroup map of the study area.

2.4.1. Terraza model

The Terraza model predicts bio-climatic limitations of typical Mediterranean crops grow in specific regions. This model is dependent on current climate data and crop response data, including the coefficient of photosynthetic efficacy (Kc), the coefficient of efficiency (Ky), and soil water retention.

Calculations

The Terraza model evaluates the water deficiency of a site mainly from climatic factors as well as other factors, such as type of plant, so the evaluation of a single land unit may differ depending on its current use. Water deficiency and reduction in yield were determined by applying monthly rainfall and temperature data for a period of 40 years (1966–2005) and 10 years (2015–2006). The monthly crop evapotranspiration (ET^o) was calculated using the Thornthwaite method (Thornthwaite, 1948).

The monthly evapotranspiration of the crop (ETc) was then calculated from ET^o as follows:

$$ETc = ET^o \times Kc \quad (1)$$

where: Kc is the monthly coefficient of the crop. Finally, the monthly real evapotranspiration (ETa) was given by:

$$Eta = ETc - D \quad (2)$$

where: D is the monthly water deficit of the site.

The difference between evapotranspiration and precipitation at a site can be positive or negative. If it is positive, there is a surplus or excess of water; if it is negative, there is a deficiency or lack of water. During a crop's GS, this difference was calculated based on the amount of precipitation and the ETc of the crop.

Reduction in yield

Prediction of the reduction in yield was achieved by employing a simple, linear crop-water production function, which was found by Equation 3. This formula enables the degree of sensitivity to water to be taken into account when estimating yield reductions for various crops and growth stages based on the soil moisture status. ETa is the main indicator of water shortage.

The monthly reduction in crop production (Ry) was calculated using the following formulas (FAO, 1986):

$$1 - Ya/Ym = Ky\,(1 - ETa/ETc) \quad (3)$$

$$1 - Ya/Ym = Ry \quad (4)$$

$$Ry = Ky\,(1 - ETa/ETc) \times 100 \quad (5)$$

where: Ya is the real crop production, Ym is the potential crop production, and Ky is the coefficient of crop efficiency. The annual reduction in crop production (Rys) was calculated as follows:

$$Rys = Kys\,(1 - \Sigma ETa/ \Sigma ETc) \times 100 \quad (6)$$

where: Kys is the coefficient of seasonal reduction, ΣETa is the sum of the monthly real evapotranspiration during the crop's growth period, and ΣETc is the sum of the monthly evapotranspiration of the crop during its growth period.

The crop response factors (Ky) correlate the relative yield decrease to the relative evapotranspiration deficit caused by a lack of adequate water. The Ky values are obtained through empirical experiments.

The maximum and minimum values of temperature (°C) and precipitation (%) related to climatic factors can be added to the previous figures as climate change models extracted by the Terraza model. From the range of annual reduction in crop production (Rys), four classes of water deficiency were established: H1–H4.

2.4.2. Cervatana model

As a subset of the MicroLEIS DSS, the Cervantana model, forecasts agricultural land use capability for a wide series of possible agricultural uses. It compares the values of the characteristics of the land-unit to be evaluated with the generalization levels established for each use capability class. The prediction of land use capability is the result of a qualitative evaluation process or overall interpretation of the following biophysical factors: relief, soil, climate, and current use or vegetation (De la Rosa et al., 2001).

The procedure of maximum limitation is used, with matrices of degree, to relate the land characteristics directly to the classes of land use capability (De la Rosa et al., 2001). In each case, the most limiting criteria (up to a total of three) are given priority. The control section of soil observations for applying the Cervatana model ranged between 0 cm and 50 cm. By integrating MicroLEIS DSS with GIS techniques, it is possible to expand the land evaluation results from one specific point to wider geographic areas using a soil survey and other related maps. In the present study, ArcGIS 10.3 was used to integrate the soil data with the results obtained from the model and the presentation of the georeferenced land capability maps.

The results of the Cervatana model depend on the output results obtained from the Terraza model (e.g., the water deficit class and the risk of frost class). The land units are grouped into four classes. The first three classes (S1, S2, and S3) include land in response to capable agricultural usage, while class N refers to land that is more appropriate for forestry and pasturage. The land unit is then assigned to a subclass determined by the most limiting land qualities (Aldabaa et al., 2010). The following limiting factors were selected: site, soil, erosion risk, and bioclimatic deficiency. The land capability evaluation classes and subclasses are summarized in Table 4.

3. RESULTS AND DISCUSSION

3.1. Climate perturbation

The results of the CDBm program calculations for climate change, and their perturbations, are shown in Table 5. The summaries of the water balance components calculated using the CDBm program of MicroLEIS DSS for the long-term future scenarios (the 2080s) for the Miandoab synoptic station are graphically shown in Figure 3.

Analysis of long-term climate change shows that temperature, precipitation, evapotranspiration, aridity, the ARi and duration of the GS will increase, while the HUi will decrease.

This means that, in spite of increased rainfall, drought will be the main problem confronting agricultural land use in the 2080s.

3.2. Reduction in crop production

Bioclimatic deficiency was calculated by applying the Terraza model to wheat, alfalfa, and sugar beets. The Terraza modelling approach predicted that the results were approximately the same for both the past (1966–2005) and present (2006–2015) scenarios. Therefore, we considered two scenarios: current and future. This approach also revealed that short-term and long-term futures have the same outputs.

Currently, wheat, alfalfa, and sugar beets have a 26%, 61%, and 82% reduction in yield (H2, H3, and H4 classes); however, these reductions will change to 22%, 57%, and 79% in the long term future scenario, respectively (Figure 4). In the present study, the variable, frost risk, was not taken into consideration and the reduction in yield was only estimated based on the water stress values.

Table 4. Land capability evaluation classes and subclasses

Classes	Subclasses
S1 = Excellent	Slope = t
S2 = Good	Soil = i
S3 = Moderate	Erosion risks = r
N = Marginal	Bioclimatic deficit = b

Table 5. CDBm results, Miandoab synoptic station data for the future scenario (2080s)

Months	Tm	Tmax	Tmin	P	Pmax	ET°	Hui	Ari	GS	Mfi	Aki
January	5.2	10	0.4	21.3	8	3.9	---	---	---	---	---
February	8.4	13.8	2.9	7.7	13.6	10.4	---	---	---	---	---
March	12.8	19	6.6	27.5	11	30.6	---	---	---	---	---
April	16.9	22.7	11.1	34.7	11.1	58.2	---	---	---	---	---
May	22.4	30.1	14.7	15.3	6.9	116	---	---	---	---	---
June	27.3	36.1	18.5	3.3	2.4	139.5	---	---	---	---	---
July	31.3	40	22.5	1.9	1.5	168	---	---	---	---	---
August	31.1	40.4	21.8	1.1	1	168	---	---	---	---	---
September	26.8	36.2	17.3	9.7	5.6	135	---	---	---	---	---
October	19.6	27.5	11.6	70.3	25.9	69.9	---	---	---	---	---
November	12.8	18.7	6.8	82.8	47.2	25.3	---	---	---	---	---
December	7.4	12.6	2.2	40.8	15.3	7.9	---	---	---	---	---
Annual	18.5	25.6	11.4	316.4	149.5	932.7	0.34	8	12	51	108.3

Tm: mean temperature, Tmax: maximum temperature, Tmin: minimum temperature, P: precipitation, Pmax: maximum precipitation per day, ETo (T): evapotranspiration calculated using the Thornthwaite method, HUi: humidity index, ARi: aridity index, GS: growing season, MFi: modified Fournier index, AKi: Arkley index.

Table 6. Irrigation with use efficiency of 48.4% for the crops in the present climate conditions in the study area

Crop	Irrigation $m^3 ha^{-1}$	No. ofIrrigations	Irrigation months	Sowing time
Wheat	8384	4-5	October-July	Oct
Alfalfa	17479	8-12	April-October	Apr
Sugar beet	16455	8-10	May-October	May

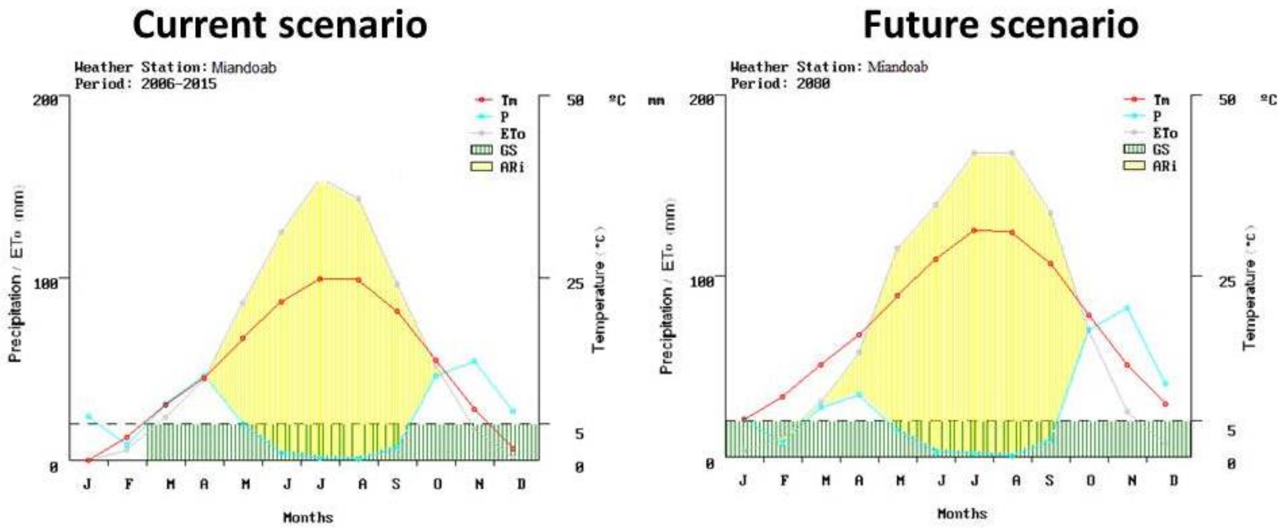

Figure 3. Graphic representation of climate for the study area (future scenario). Tm: mean temperature; P: precipitation; GS: growing season; ET°: potential evapotranspiration, Ari: aridity index

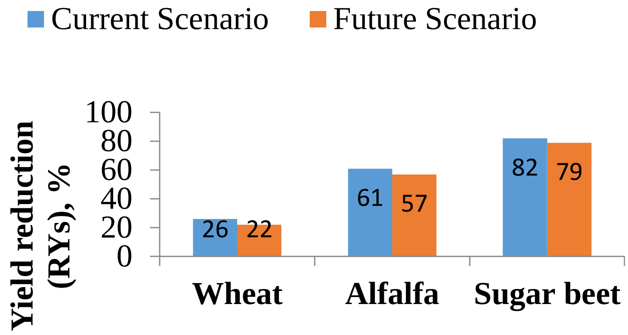

Figure 4. A comparison of the annual reduction in yield under rainfed conditions for current and future scenarios H1= <20%; H2= 20–40%; H3= 40–60%, H4= >60%.

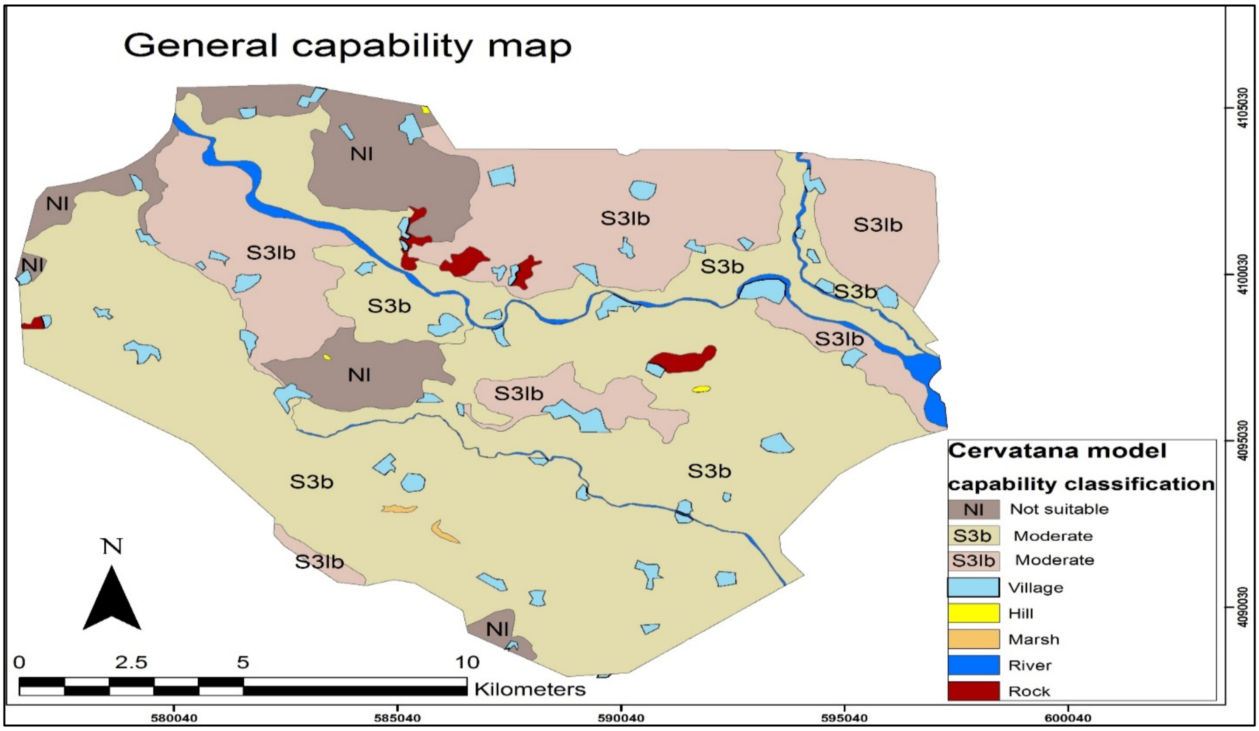

Figure 5. General capability map of the study area.

The results show that the current water deficit in the study area will be reduced as a result of climate change in 2080s for all crops except alfalfa. Sugar beets had the highest percentage of yield reduction.

3.3. Cultivation conditions

We assessed two rainfed and irrigated conditions. In the first condition, the reduction in yield decreased as a result of climate change for all the studied crops, as follows: wheat< alfalfa <sugar beets. The climate perturbation effects on the rainfed conditions showed a positive impact on wheat and sugar beets. The yield reduction will decrease in the long term scenario for these crops, although the general classification will remain constant. However, the reduction in yield for alfalfa will change from H3 to H4. In the second condition, water supplementation in the Miandoab area is sufficient for cultivation of all crops (Table 6).

The results demonstrate that the climate perturbation effects are more serious for the rainfed conditions than the irrigated conditions in the area. Thus, the cultivation of rainfed wheat should replace the cultivation of irrigated wheat.

3.4. Land capability

The land capability approach (sometimes also referred to as land suitability) identifies the potential to use an area of land for different purposes or management practices (Iain Brown, et al., 2008). Internationally, many studies have considered the impacts of climate change on future agricultural land use through scenario (Ewert et al., 2005). According to the Cervatana model results, 89.92% of the total area was distinguished as moderately suitable land (S3b and S3lb), while 10.07% of the area was classified as unsuitable (Nl) land, due to soil salinity and bioclimatic deficiency limitation factors.

Following the land evaluation process, the unsuitable land determined by the Cervatana model can be established as rangeland or forest to prevent soil degradation. The Cervatana (land capability) model results for each profile are shown by Fig.5.

The major limitation in classifying the suitability of the area was bioclimatic deficit (water deficit), which was altered by climate change and soil salinity. The results show that bioclimatic deficiency affects the suitability of the crops in this study area for rainfed cultivation in both of the hypothetical scenarios (current and future situations). Moreover, the reduction in yield observed for most of the crops is due to the decrease in precipitation during the mid-stage of the growth period. Therefore, the planting dates can be changed from April/May to July because at the beginning of that growing period the demand for water is low. The current suitability status of any type of land can be impacted by climate change; the limiting factor is the reduction in yield due to bioclimatic deficiency. Accordingly, a decrease in precipitation and an increase in evapotranspiration occurs; consequently, water deficiency may limit the production of specific crops in 2080s.

4. CONCLUSION

The study aimed to evaluate the impact of climate change on land capability for rainfed and irrigated crop production in order to achieve sustainable agriculture. Bioclimatic deficiency was the main limitation factor caused by climate change in the Miandoab Plain area. The meteorological parameters showed that the study area will be impacted by climate perturbation. Moreover, all the evaluated crops responded to climate change. The bioclimatic deficiency classes (H2, H3, and H4) observed in more than 88% of the study area was moderately suitable for all the studied crops.

The results of the applied models demonstrate that climate change has an impact on bioclimatic deficiency. Thus, climate change will exacerbate land capability in the Miandoab area.

As expected, wheat in irrigated and rainfed conditions had the same land capability classes; rainfed wheat cultivation is recommended over irrigated wheat to ensure safe natural resources. Moreover, the impact of climate change on rainfed alfalfa and sugar beet cultivation is more relevant than the irrigated ones in the study area.

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