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Vulnerability assessment of wheat and maize production affected by drought and climate change

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ABSTRACT

Agricultural vulnerability can be referred to the degree that agricultural systems may experience harm due to a stress. A simulation study was conducted to assess the vulnerability of wheat (irrigated and rainfed) and maize production due to drought and climate change in the Northeast of Iran. UNEP Aridity Index (AI_U) was calculated to measure drought situation in five agricultural centers including Birjand, Bojnourd, Mashhad, Sabzevar and Torbat Heydarieh. Projected changes in climate variables were simulated by two General Circulation Models: HadCM3 and IPCM4 under three scenarios (A1B, A2 and B1), simulated by LARS-WG. The Cropping System Model (CSM)-CERES-Wheat and (CSM)-CERES-Maize were used for crop growth simulation under projected climate conditions. In order to quantify the magnitude of vulnerability to varying drought conditions, vulnerability was considered as a function of sensitivity, well-being state relative to its damage threshold and exposure. Vulnerability was calculated considering severe droughts in the selected years and the expected vulnerability considering the expected frequency of drought. The results showed that in all the study locations the wheat and maize production have been affected extremely by severe droughts during the base period and both crops were extremely sensitive to drought. It was also projected that crop production will be extremely vulnerable to probable droughts during the projected years the same as the base period.

1. Introduction

Vulnerability assessment of agricultural crops is an effective approach to realize the impacts of climate change and extreme climatic events on agricultural systems. Vulnerability definition differs based on subject and study orientation. Vulnerability was defined as the capacity of individuals to respond to, recover from or adapt to livelihood stress as a result of the impacts of such environmental change [1]. It was also considered as the likelihood that an individual to be exposed and adversely affected by a hazard [2]. In recent years vulnerability was generally considered as a function of exposure, sensitivity and adaptive capacity [3–5]. Sensitivity reflects the degree to which a given system responds to the fluctuations in stress, either positively or negatively [3,6]. Adaptive capacity has been defined as the capacity of a system to adjust to the change and take advantage from it [3,7,8]. Exposure is the possibility of the system being exposed to the concerned change in the stress [3,4]. In developing countries, drought vulnerability constitutes a threat to livelihoods, the ability to maintain productive systems, and healthy economics. Drought vulnerability is different for different individuals, regions and nations [9]. Defining a set of indicators [7] is one of the typical methods to

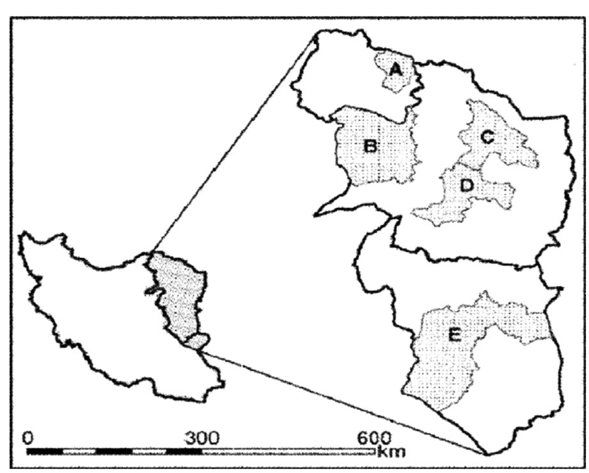

Fig. 1. Geographical study locations (A) Bojnourd, (B) Sabzevar, (C) Mashhad, (D) Torbat Heydarieh, (E) Birjand [45].

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Table 1
Latitude (Lat), longitude (Long), elevation (Elev), and annual average of climate variables for the study sites in Iran.

site	Lat	Long	Elev (m)	Average Temperature (°C)		Total precipitation (mm)	Time period
				Min.	Max.		
Birjand	32° 52′ N	59° 12′ E	1491	8.2	24.3	165.4	1961–2009
Bojnourd	37° 28′ N	57° 19′ E	1091	6.9	19.6	265	1977–2009
Mashhad	36° 16′ N	59° 38′ E	999	8.3	21.6	256.5	1961–2009
Sabzevar	36° 12′ N	57° 43′ E	977	11.8	24.7	197.8	1961–2009
Torbat Heydariyeh	35° 16′ N	59° 13′ E	1450	7.5	20.4	276.6	1961–2009

Table 2
Calculated genetic coefficients of Sardari cultivar (Rainfed wheat) [40] and three cultivars of irrigated wheat [52].

Cultivar	P1V	P1D	P5	G1	G2	G3	PHINT
Sardari	1	40	450	13	41	1.5	60
Roshan	8	58	620	16	34	1.1	87
Falat	5	60	650	18	38	1.2	87
Ghods	3	54	600	15	32	1.1	89

P1V: Days at optimum vernalizing temperature required to complete vernalization, P1D: Percentage reduction in development rate in a photoperiod 10h shorter than the threshold relative to that at the threshold, P5: Grain filling (excluding lag) phase duration (°C.d), G1: Kernel number per unit canopy weight at anthesis, G2: Standard kernel size under optimum conditions (mg), G3: Standard, non-stressed dry weight (total, including grain) of a single tiller at maturity (g), PHINT: Interval between successive leaf tip appearances (°C.d).

Table 3
Calculated genetic coefficients of maize cultivar 'Single Cross 704' [53].

P1	P2	P5	G2	G3	PHINT
250	0.1	600	700	17	30

P1: Thermal time from seedling emergence to the end of the juvenile phase expressed in degree days above a base temperature of 8 °C during which the plant is not responsive to changes in photoperiod, P2: Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 h), P5: Thermal time from silking to physiological maturity (expressed in degree days above a base temperature of °C. d), G2: Maximum possible number of kernels per plant, G3: Kernel filling rate during the linear grain filling stage and under optimum conditions (mg day^{-1}), PHINT: Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances.

Table 4
The classes of aridity index used in this study.

UNEP	Climate class
$AI_U \le 0.05$	Hyper-arid
$0.05 < AI_U < 0.2$	Arid
$0.2 < AI_U < 0.5$	Semi-arid
$0.5 < AI_U < 0.65$	Sub-humid
$AI_U \ge 0.65$	Humid

Table 5
The classes of SEN, V_{EXPS}, V_{EXPL}, EV_{EXP}, T_{EXP} and EEXP [41].

EEXP		V_{EXPL}, V_{EXPS} and EV_{EXP}		SEN	
0–1	Low	< 5	Low	< 50	Low
1–1.5	Slight	5–10	Slight	50–100	Slight
1.5–2	Moderate	10–15	Moderate	100–150	Moderate
2–2.5	High	15–20	High	150–200	High
> 2.5	Extremely high	> 20	Extremely high	> 200	Extremely high

Table 6
Comparison of simulated and observed minimum and maximum temperatures (T_{min} and T_{max}) and precipitation simulated by LARS-WG by Root Mean-squared Error (RMSE), Root Mean Deviation (RMD) and R^2 values during the base period.

Station	Parameters	RMSE	RMD	R^2
Birjand	T_{min}	2.52	0.56	0.90
	T_{max}	1.33	0.41	0.58
	Precipitation	5.16	9.40	0.96
Bojnourd	T_{min}	2.91	0.57	0.83
	T_{max}	2.43	1.16	0.92
	Precipitation	6.80	9.93	0.60
Mashhad	T_{min}	2.41	0.57	0.89
	T_{max}	1.71	0.61	0.74
	Precipitation	3.43	9.71	0.93
Sabzevar	T_{min}	1.46	0.24	0.48
	T_{max}	1.26	0.38	0.78
	Precipitation	6.34	6.98	0.96
Torbat Heydarieh	T_{min}	2.72	0.74	0.96
	T_{max}	1.16	0.28	0.75
	Precipitation	6.38	8.50	0.96

quantify vulnerability, which was used in the present study. In this method the agricultural system is considered as the hazard affected body and a series of vulnerability indicators are constructed. Many researchers have studied vulnerability considering different approaches such as [4,7,10–15]. Vulnerability and adaptation of rainfed agriculture to climate change and variability in semi-arid condition of Tanzania was studied and the vulnerability of rainfed agriculture to the effects of climate change was reported [16]. The vulnerability of rainfed maize in southern Malawi was evaluated and showed that the drought conditions in February and early March lead to most damage to maize yields in this region [17]. The study on vulnerability of crops to drought in Ghana using rainfall, yield and socio-economic data showed that the vulnerability of crop production to drought has discernible geographical and socioeconomic patterns, with the northern, upper west and upper east regions being the most vulnerable [18]. Evaluation of climate change, vulnerability and adaptation in the North Africa especially in Morocco showed that climate change will likely have the strongest effect on Morocco where the agricultural sector is of high importance for the country's economy and particularly for poor people [19].

Climate change and its potential effects on frequency and severity of extreme climatic events like drought is a concerning matter. Climate change has a profound influence on crop production sustainability in arid and semi-arid environments [20]. A more arid climate is usually accompanied by an increase in the frequency and severity of droughts [21]. An increasing trend of drought has been indicated by several studies in various locations such as the Mediterranean region [22,23], eastern China [24],

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