Climate and Development

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tcld20

Typology of vulnerability of wheat farmers in Northeast Iran and implications for their adaptive capacity

Saeedeh Nazari Nooghabi , Luuk Fleskens , Diana Sietz & Hossein Azadi

To cite this article: Saeedeh Nazari Nooghabi , Luuk Fleskens , Diana Sietz & Hossein Azadi (2020) Typology of vulnerability of wheat farmers in Northeast Iran and implications for their adaptive capacity, Climate and Development, 12:8, 703-716, DOI: 10.1080/17565529.2019.1679072

To link to this article: https://doi.org/10.1080/17565529.2019.1679072

Published online: 31 Oct 2019.

CLIMATE AND DEVELOPMENT
2020, VOL. 12, NO. 8, 703–716
https://doi.org/10.1080/17565529.2019.1679072

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS Check for updates

Typology of vulnerability of wheat farmers in Northeast Iran and implications for their adaptive capacity

Saeedeh Nazari Nooghabi [a,b], Luuk Fleskens [c], Diana Sietz [c,d] and Hossein Azadi [e,f,g]

[a]Agricultural Extension and Education, Tarbiat Modares University, Tehran, Iran; [b]Persian Daroo-e-Alborz Research and Technology Fund Institute, Tehran, Iran; [c]Soil Physics and Land Management Group, Wageningen University and Research, Wageningen, The Netherlands; [d]Potsdam Institute for Climate Impact Research, Member of the Leibniz Association, Potsdam, Germany; [e]Department of Geography, Ghent University, Ghent, Belgium; [f]Research Group Climate Change and Security, Institute of Geography, University of Hamburg, Hamburg, Germany; [g]ISUMADECIP, Faculty of Environmental Science and Engineering, Babeş-Bolyai University, Cluj-Napoca, Romania

ABSTRACT

This study is focused on understanding sources and patterns of vulnerability of wheat smallholder farmers in Northeast Iran. We conducted a farm household survey and recorded multiple environmental and socio-economic attributes of 391 wheat smallholder farmers. A Vulnerability Scoping Diagram and Principal Component Analysis served to identify key factors determining wheat farmer's vulnerability. Also, we performed a cluster analysis to classify wheat farmers into three vulnerability types. Although drought affects all types as main environmental stressor, only for Cluster 2 was it the key vulnerability factor. For Clusters 1 and 3 socio-economic vulnerability components prevailed: for farmers categorized in Cluster 1 land consolidation was the main problem, while the current wheat import policy was the key problem for Cluster 3 farmers. Multiple tailored policies are needed that reduce the vulnerability of wheat farmers in all clusters. Supportive government policies should for example focus on avoiding price distortions from wheat imports for Cluster 3, land consolidation for Cluster 1 and collective tackling of pests and weeds for Cluster 2. Simultaneous provision of farm advisory services will benefit farmers of Clusters 1 and 3, while availability of improved seeds (drought-tolerant varieties) and other inputs will lower the environmental vulnerability of all farmers.

ARTICLE HISTORY
Received 14 January 2018
Accepted 8 October 2019

KEYWORDS
Socio-ecological; climate risk; patterns; vulnerability scoping diagram; wheat farmers

1. Introduction

In recent years, the effects of extreme weather events on primary production and livelihoods that depend on it have become increasingly visible around the world as well as in Iran. Because of this, research into vulnerability has proliferated, the priority of which is to address the development and implementation of adaptation policy (Hinkel, 2011; IPCC, 2007). Better understanding societies' vulnerability is a prerequisite for ensuring food and livelihood security by minimizing adverse impacts of extreme weather events and other hazards on farming systems (Kok et al., 2016) and increasing resilience to disasters (Birkmann, 2006; Kappes, Papathoma-Kohle, & Keiler, 2012).

While several scholars have focused on climatic variability as key source of vulnerability, there is a need to better understand vulnerability at a systemic level, at which there is a dynamic interplay of environmental and socio-economic factors driving vulnerability of farming systems. An essential step in coping with natural or man-made hazards is therefore the identification of the most vulnerable areas and societal groups and the main drivers of vulnerability (Kok et al., 2016; Reidsma, 2007; Reidsma & Ewert, 2008; Yingchun et al., 2015). Importantly, vulnerability can vary greatly across space (Cutter & Finch, 2008; Khan, 2012; Kok et al., 2016), depending on economic, social, geographic, demographic, cultural, institutional governance and environmental factors (Yingchun et al., 2015). Thus, underlying conditions need to be explored within a given locality or region.

A primary challenge of vulnerability assessment is the identification of appropriate indicators that suitably capture the environmental and socio-economic characteristics of a community or a place (Rajesh, Jain, Sharma, & Bhahuguna, 2014). There is a need to assess multi-faceted agricultural vulnerability at regional scale. Recent studies indicated that there are recurrent combinations of socio-ecological factors that lead to the vulnerability of smallholder farmers in drylands around the world (Kok et al., 2016; Panda, 2016; Sietz, 2014; Sietz et al., 2017). For example, people living in the drylands of Iran face increasing pressures on natural resources due to a growing population, limited and insecure access to water and fertile soils, and poor infrastructure that impedes market linkages (Keshavarz, Maleksaeidi, & Karami, 2017).

In this paper, we focus on the vulnerability of wheat farmers in Khorasan Rasavi Province, a prime wheat production area in Iran. In recent years, Iranian wheat farmers have been confronted with temporally and spatially varying environmental and socio-economic stresses including extreme temperatures, prolonged drought, erratic precipitation, population growth, chronic water shortage, increasing economic inequality, changes in national agricultural policies, insufficient technology

CONTACT Luuk Fleskens luuk.fleskens@wur.nl

and weak management (Jalal Kamali, NajafiMirak, & Asadi, 2012). Adaptation to these problems requires a systemic assessment of wheat farmers' vulnerability.

Iran is one of the greatest wheat importers in the world that experienced a short period of self-sufficiency in 2004 (Deihimfard, Zand, Mahdavi Damghani, & Soufizadeh, 2007; Faramarzi, Yang, Schulin, & Abbaspour, 2010), but reclined back to its old trend of importing more wheat in the face of a protracted drought. While Iranian wheat farmers have had to deal with crop yield reductions induced by climatic variability (Jalal Kamali et al., 2012), a decline in wheat prices and a change in subsidy policies also increased farmers' vulnerability (Luers, Lobell, Sklar, Addams, & Matson, 2003). Wheat is a strategic crop for food security in Iran, and it is the objective of the Iranian Agricultural Jihad Ministry to harvest more than 11 million tons of wheat in the future in order to reduce wheat imports and reach self-sufficiency. The primary strategy to reach this goal is to raise the average national productivity of the area under irrigated wheat (2.3 million hectares) to 5.5 tons per hectare. However, it is unlikely that a narrow focus on irrigation will reduce the vulnerability of wheat farmers.

The purpose of this paper is (i) to identify environmental and socio-economic factors determining the vulnerability of wheat farmers at farming system level, and (ii) to classify wheat farmers according to their environmental and socio-economic vulnerability aspects. To address these objectives, this paper applies the Vulnerability Scoping Diagram (VSD) and Principal Component Analysis (PCA) in order to identify the key variables that represent each of the three dimensions of vulnerability (exposure, sensitivity, and adaptive capacity). Subsequently, we perform a cluster analysis to classify wheat farmers in typical vulnerability patterns.

2. Patterns of vulnerability

Vulnerability is an abstract concept and many studies have stressed the need for clear, contextual conceptualizations and have defined the term 'vulnerability' according to their fields of study (Dunford, Harrison, Jager, Rounsevell, & Tinch, 2015; Khazai, Merz, Schulz, & Borst, 2013; Nazari, Pezeshki Rad, Sedighi, & Azadi, 2015; Rajesh et al., 2014; Wolf & McGregor, 2013). This study uses the following definition of vulnerability: 'the extent to which environmental and economic changes influence the capacity of regions, sectors, ecosystems, and social groups to respond to various types of natural and socio-economic shocks' (Leichenko & O'Brien, 2002, p. 3). Vulnerability should be understood as a dynamic concept as its three components: exposure, sensitivity and adaptive capacity may be influenced by a range of context-specific biophysical and socio-economic factors (Nazari et al., 2015). Exposure is the degree to which a system or group experiences environmental or socio-economic stress, while sensitivity refers to the degree to which a system or group is affected by exposure to stresses (McCarthy, Canziani, Leary, Dokken, & White, 2001). Adaptive capacity is defined as the capability of a system to adjust its behaviour and characteristics so as to enhance its ability to cope with environmental and socio-economic stresses (McCarthy et al., 2001).

Key vulnerability indicators in published studies have been characterized based on assumptions about the factors and processes that lead to vulnerability and are informed by understanding the interactions between humans and the environment. Selecting the main factors of vulnerability for each study depends on the context, nature of the system and the type of hazard (Brooks, Adger, & Kelly, 2005). The recurrence of interacting environmental and socio-economic drivers of vulnerability has motivated extensive research on the typical patterns of vulnerability at local, regional and global scales (Aleksandrova, Gin, & Giupponi, 2016; Oberlack et al., 2019). Focusing on drylands, coastal areas, contaminated sites and other human-environmental systems (Jäger et al., 2007; Kok et al., 2016; Sietz, 2014; Sietz, Ludeke, & Walther, 2011), pattern analysis has provided a systematic approach to assessing archetypical vulnerability situations in a range of contexts, while taking multiple stressors and related outcomes into consideration. Essentially, vulnerability patterns reveal recurrent conditions in a multitude of observations in order to highlight typical mechanisms that create vulnerability (Kok et al., 2016; Sietz et al., 2017). This study uses pattern analysis (clustering and factor analysis) to improve our understanding of vulnerability of wheat smallholder farmers in Northeast Iran in order to devise adaptive strategies for coping with increased levels of risk.

3. Methodology

3.1. Study area

Wheat is the staple food crop in Iran cultivated on more than 60% of the country's arable lands (Amid, 2007; Faramarzi et al., 2010). Wheat is grown in about 6.1 million ha in Iran, of which 2.3 million ha are irrigated and 3.8 million ha are rain-fed. This study focuses on irrigated wheat that occupies about 38% of the wheat-cultivated area and produces more than 66% of the country's wheat production, i.e. it plays a significant role in the national wheat production of Iran (Iranian Statistics Centre, 2015).

During the last decade, wheat grain yields and production in rain-fed and irrigated areas in Iran has stagnated or, in some areas, even declined. The country has faced a number of extreme droughts in the last decade that have resulted in limited water for irrigation, erratic amounts and distribution of rainfall, soil degradation, and warmer temperatures (Jalal Kamali et al., 2012; Khoshnodifar, Sookhtanlo, & Gholami, 2012). These issues are exacerbated by the limited use of high yielding varieties, poor crop management, and inadequate supply and delayed input availability (fertilizer, herbicides) (Jalal Kamali et al., 2012).

Khorasan Razavi is a province in Northeastern Iran, occupying an area of more than 116,000 km^2. The province consists of 28 counties, 70 districts and 164 rural districts (Iranian Statistics Centre, 2012; Figure 1). The total population of wheat farmers in the Khorasan Razavi Province is 130,000. Despite being one of the major wheat producing provinces in Iran, low wheat yield levels is the main drawback: there is a large gap between record maximum performances (12 tons ha^{-1}) and the average yield obtained in this province (about 3.5 tons ha^{-1}) (Iranian Statistics Centre, 2012). Furthermore,

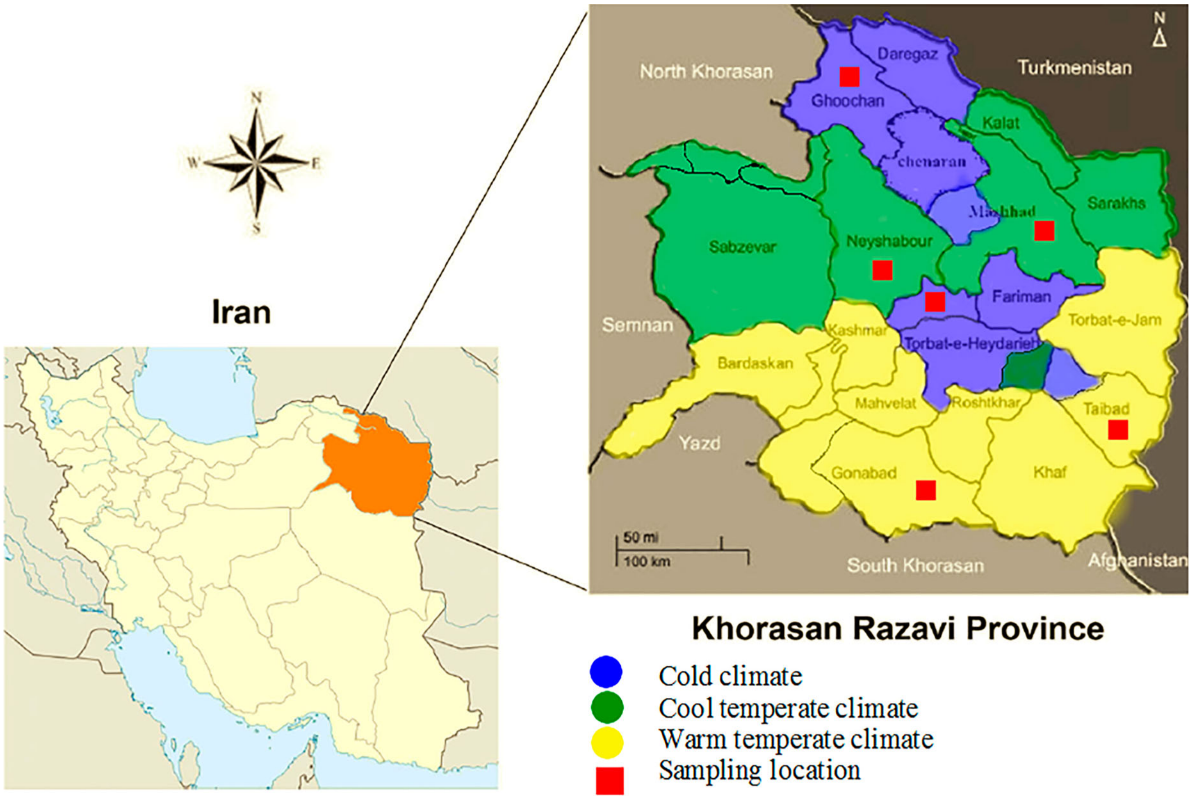

Figure 1. Study locations and their climatological attributes.

there is high regional yield variability within the province, propelled by local socio-economic and environmental factors that determine the vulnerability of wheat farmers.

3.2. Indicators of vulnerability

Nazari et al. (2015) identified several environmental and socio-economic indicators that reflect the three dimensions of wheat farmers' vulnerability: exposure, sensitivity, and adaptive capacity. We used these indicators in this study as they represent the main socio-economic and environmental factors that influence farmers' vulnerability through a variety of farming system components (Table 1), as further explained below.

Exposure: abiotic and biotic stresses; Wheat is constantly exposed to the varying stresses of abiotic and biotic factors, such as *drought*, *salinity*, *cold*, *heat*, *haying-off*, as well as those factors' effects such as: lack of good distribution of rainfall, dry end of season, early dry season, cold early spring, and prevalence of diseases, pests and weeds, which significantly impact wheat production (Jalal Kamali et al., 2012; Khoshnodifar et al., 2012; Xiao et al., 2015). Abiotic stress factors significantly decreased agricultural yields, and their effects are bound to worsen with a changing climate in the coming decades (Spinoni, Naumann, & Vogt, 2017; Wang & Frei, 2011). Indeed, abiotic stressors such as drought, cold and heat cause wheat yields reductions by more than 50% and create conditions for the development of biotic stressors (including diseases, pests and weeds). For instance, increasing temperature facilitates the spread of pests, attacks on crops (Sahu, Dehury, Kumar Modi, & Barooah, 2014), and combined heat, humidity and wind, which leads to haying-off and damage to plant tissues. Common biotic stressors in Iran include the following *diseases*: yellow rust, leaf rust; *pests*: sunn, wheat stem saw fly, cereal leaf miner, cereal leaf beetle, and cereal ground beetle; and *weeds* (broad leaves and narrow leaves) (Jalal Kamali et al., 2012; Khoshnodifar et al., 2012).

Sensitivity; Recent studies have indicated that socio-economic driving forces can affect the yield of farmers (Jiao & Moinuddin, 2016; Navarra & Tubiana, 2013; Tate, 2012). For example, ever-increasing *costs of production* force farmers in Tuscany to intensify production (Navarra & Tubiana, 2013).

Table 1. Indicators of wheat farmers' exposure, sensitivity and adaptive capacity (Nazari et al., 2015).

Vulnerability dimensions	Indicators	Components
Exposure	Abiotic stressors	Drought, salinity, cold, heat, and haying off
	Biotic stressors	Diseases, pests and weeds
Sensitivity	Human capital	Education, demographic factors, farm labour, work experience
	Financial capital	Household incomes and income sources, size of farm operation, land ownership and tenure security, cost of production, technology
	Natural capital	Land and water quantity and quality
Adaptive Capacity[a]	Human capital	Farm management[a]
	Social capital	Social networks and governmental support[a], market channels
	Social equity	Equitable access to resources, institutions
	Physical capital	Basic infrastructure and services

[a]Adaptive capacity and sensitivity indicators and components are often difficult to disentangle. Specific components of adaptive capacity are emerging from the results; these mainly concern farm- and government-level decision-making attributes.

Environmental and socio-economic driving forces also affect each other (Rurinda et al., 2014). To illustrate, decreased precipitation causes increased demand for *scarce water resources*, which subsequently creates obstacles for reducing regional vulnerability of socio-economic systems to climate change. Farmers should consider such multi-faceted climatic and socio-economic changes simultaneously when adjusting their operations.

Adequate *education and literacy levels* of farmers enables them to have access to information and reduces their vulnerability by enhancing their ability to cope with adversity (Leichenko & O'Brien, 2002). Also, available *farm labour*, especially during the peak working seasons, alleviates their susceptibility (Sangpenchan, 2011). A flexible and responsive *farm management* strategy is one of the main factors that decreases farmers' vulnerability to changes. Several studies have shown examples of farm level climate change adaptation practices that smallholder farmers can adopt (Harvey et al., 2013; Lavorel et al., 2015; Lebel, Fleskens, Forster, Jackson, & Lorenz, 2015; Rurinda et al., 2014; Vignola et al., 2015). As a vivid illustration, planting earlier or altering irrigation and fertilization frequencies and schedules may allow farmers to better exploit cropping seasons (Feng et al., 2007; Lobell, Ortiz-Monasterio, Addams, & Asner, 2002; Yang et al., 2007). Crop rotation precludes various problems, including outbreaks of pests, diseases and weeds, unbalanced distribution of manpower and machinery input requirements, and soil erosion. Additionally, the role of winnowing and the use of disinfected and certified seeds in decreasing farmers' vulnerability should be considered by farmers when selecting wheat varieties adapted to local circumstances.

Adaptive capacity; Other important factors that mitigate farmers' vulnerability are *governmental support* and policy interventions in service delivery and seed production, *land consolidation* policies, wheat import policy, declaring good and acceptable guaranteed prices to farmers based on international prices, determining the price of wheat before cultivation, and stabilizing the price for other crops (for instance, barley) that are in competition with wheat. For example, in a given year, if the price for barley has more benefits for them, farmers prefer to cultivate barley instead of wheat. In Iran, wheat is considered a strategic crop and the policies play a particularly important role: as an illustration, farmers can sell their grains in the *market* if they like, but if they fail, government buys their grains at a guaranteed price (Jalal Kamali et al., 2012).

This study considers a number of farmers' characteristics that have, in some vulnerability studies, been assessed and found to reduce or increase vulnerability, including: *age* and *work experience* (Jalal Kamali et al., 2012; Khoshnodifar et al., 2012), *non-agricultural income* (Brooks et al., 2005; Deressa, 2010; Sangpenchan, 2011; Zarafshani et al., 2012), *total cultivated area* (Deininger & Feder, 2001; Deressa, 2010), *cultivation area of irrigated wheat* and yield of irrigated wheat (Jalal Kamali et al., 2012; Khoshnodifar et al., 2012), *income from agricultural products* (Jalal Kamali et al., 2012; Khoshnodifar et al., 2012; Zarafshani et al., 2012), the *percentage of produce consumed* by the farmer (own consumption) and the *percentage of product* that farmers *sell* to the market (Jalal Kamali et al., 2012), *second job* (Dabi, Nyong, Adpetu, & Ihemegbulem, 2008; Osman-Elasha & Sanjak, 2008), *labour work force* (Acosta-Michlik & Espaldon, 2008; Reidsma, 2007; Simelton, Fraser, Termansen, Forster, & Dougill, 2009), *education* (Adejuwon, 2008; Chavas, 2001; Dabi et al., 2008; Füssel, 2007; Huffman, 2001; Khoshnodifar et al., 2012; Paavola, 2008; Zarafshani et al., 2012), and *number of parcels* of agricultural land (Eakin et al., 2006; Reidsma, 2007; Shrestha, 2011; Simelton et al., 2009).

3.3. Sampling and data collection

Wheat farmers were selected based on two criteria for sampling: climate and cultivated area. There are diverse climates in the Khorasan Razavi province for growing wheat, including: (1) cold climate; (2) temperate climate, subdivided in: (a) cool temperate climate; and (b) warm temperate climate (Iranian Agricultural Ministry, Khorasan Agricultural Research Center, 1997; Zarefiezabadi, Sharifi, & Beheshti, 2003). Initially, this study classified counties according to climatic zone. In each climatic zone, two counties were randomly selected.

Interviews with agricultural specialists and expert farmers were used as expert knowledge in order to classify farmers according to the cultivation area of irrigated wheat. As a result, farmers were classified into three categories: 'less than 5 ha', '5–15 ha' and 'more than 15 ha' (Table 2). Accordingly, data were collected from 6 counties, 12 districts, 26 rural districts, and 85 villages. The population of the study area consisted of 130,000 irrigated farmers, from which 391 farmers were selected as the sample using Cochran's formula (Cochran, 1977) and a multi-stage stratified random sampling technique. In order to gather the data, a questionnaire was developed. It was validated by cross-checking with the judgment of faculty members of the Agricultural Extension and Education and Agricultural Management and Development departments. The reliability of the questionnaire was examined by Cronbach Alpha coefficients, which ranged from 0.75 to 0.95 (Biotic stressors $\alpha = 0.78$, abiotic stressors $\alpha = 0.82$, management tips $\alpha = 0.95$, security and land ownership $\alpha = 0.83$, cost of production $\alpha = 0.87$, technology $\alpha = 0.86$, social networks $\alpha = 0.75$, supportive government policies $\alpha = 0.85$, market channel $\alpha = 0.86$, basic infrastructure and services $\alpha = 0.82$, land and water quantity and quality $\alpha = 0.77$). The survey was conducted from June 2014 until September 2014 and the data were analysed by SPSS software version 21.

The questionnaire consisted of three parts. The first part asked for individual characteristics (education, age, household incomes and income sources, size of farm operation of farmers etc.), the second part questioned environmental driving forces of farm vulnerability, including: climate variables (abiotic stressors such as drought, salinity, cold, heat, and haying-off and biotic stressors including diseases, pests and weeds), while the last part examined the driving socio-economic forces of farm vulnerability that consisted of variables in five capitals: (1) human (farm labour, farm management); (2) financial (land ownership and tenure security, cost of production, technology); (3) social (social networks and governmental support, market channels, social equity); (4) physical (basic infrastructure and services); and (5) natural (land and water quantity and quality). All questions relating to sources of farm vulnerability were based on the farmer's perception of the importance of each

Table 2. Sample of the study, stratified according to climate and cultivation area of irrigated wheat.

Population[a]	Climate	Sampled counties	Wheat farmers in each city[a]	Wheat farmers sampled	Cultivation area of irrigated wheat		
					<5 ha	5–15 ha	>15 ha
Irrigated wheat farmers 130,000	Cold	Jolge Rokh	3500	37	23	13	1
		Ghuchan	6070	65	25	34	6
	Warm temperate	Taiebad	6649	70	65	4	1
		Gonabad	1010	11	6	4	1
	Cool temperate	Mashhad	3093	33	24	8	1
		Neshabur	16375	174	164	9	1
		Overall	36697	390	307	72	11

[a]The number of wheat farmers in the Khorasan Razavi Province was obtained from the Iranian Agricultural Jihad Ministry.

factor in determining the farm's vulnerability during the last 5 years on a 5-step Likert-scale ranging from very high to very low. The impact of environmental stressors was thereby understood as yield damage, whereas the influence of socio-economic stressors was assessed more broadly as factors influencing farm viability, income security and manoeuvring space to cope with adverse situations.

3.4. Data analysis

A Vulnerability Scoping Diagram (VSD) and a Principal Component Analysis (PCA) were used to identify the key variables that represent each of the three dimensions of vulnerability (exposure, sensitivity, and adaptive capacity). Subsequently, a hierarchical cluster analysis technique was used to classify farmers into different vulnerable groups.

3.4.1. Vulnerability scoping diagram

Polsky, Neff, and Yarnal (2007) presented the VSD as an effective tool for facilitating vulnerability assessment by summarizing information from a case study in one place according to the three main dimensions of vulnerability: exposure, sensitivity, and adaptive responses. The centre of the diagram shows the vulnerability of a given human–environment system and the first ring includes three fundamental dimensions of vulnerability (Figure 2). The middle ring represents the components that are the abstract characteristics used to evaluate each of the dimensions. Finally, the outer ring lists observable characteristics that represent the measurements of the components of the dimensions (Coletti, Howe, Yarnal, & Wood, 2013; Polsky et al., 2007; Tuler, Webler, & Polsky, 2013). This study used evidence from literature reviews, previous researches and viewpoints of farmers to create a VSD. In analysing the three dimensions of vulnerability within the context of this study and based on our conceptual framework for wheat farmers' vulnerability assessment (Nazari et al., 2015), we found that exposure consists of changes in environmental and socio-economic factors that may cause stress to farmers. Sensitivity is understood in terms of factors such as farm labour, land ownership, household income and income sources, land and water quantity and quality, and farm size. Finally, adaptive capacity is conditioned by factors such as market channels, farm management, technology, education, governmental support, second job, institutions, social equity, infrastructure, cost of production and social network.

The next step employed a Principal Components Analysis (PCA) to identify key vulnerability indicators and variables in the case of the study area that are likely to persist in the face of an evolving climate and socio-economic system and to complete the third ring of VSD.

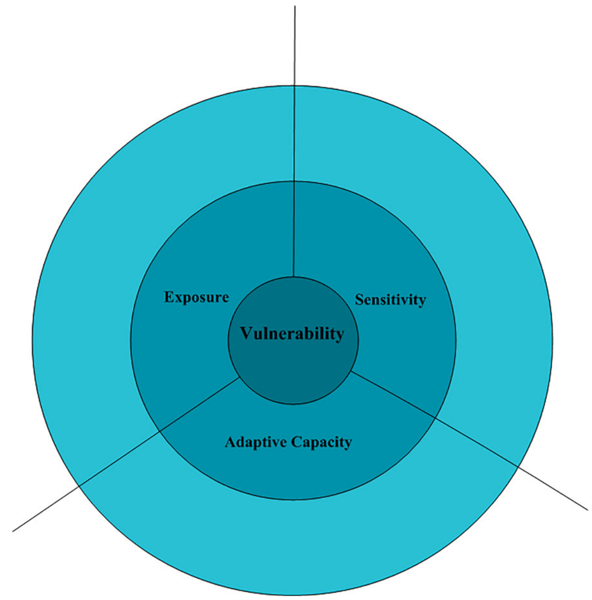

Figure 2. General form of the VSD (Polsky et al., 2007).

3.4.2. Principal component analysis

All variables were normalized using Z scores. A Principal Component Analysis (PCA) was performed to minimize the number of climate and socio-economic variables and to identify a set of variables that underlined the key vulnerability concepts of each dimension (exposure, sensitivity, and adaptive capacity) in the VSD. For testing the suitability of the variables for PCA, Kaiser-Meyer-Olkin (KMO) Test for Sampling Adequacy and Bartlett's Test of Sphericity were used. Factor loadings greater than 0.6 constituted the best decision criterion regarding the number of components retained in the analysis and to name the components based on the structure of the proxy data that made up the components. A scree plot was used to determine the number of components to include.

3.4.3. Cluster analysis

This study employed cluster analysis to categorise determinants of vulnerability. Cluster analysis has successfully been applied in order to identify typical vulnerability patterns in a range of contexts, including smallholder farming in dryland regions and urbanisation in coastal areas (e.g. Kok et al., 2016; Sietz et al., 2019; Sterzel, Lüdeke, Walther, Kok, & Lucas, in press). As an important feature, clustering allows a high-dimensional data space to be accommodated and keeps the combination of underlying conditions visible throughout the analysis so that they can be interpreted with respect to cluster-specific vulnerability.

To conduct the cluster analysis, the first three principal components (19 variables) of socio-economic indicators and the first four principal components (10 variables) of environmental indicators were used in a hierarchical cluster analysis. The study applied Ward's clustering method using a squared Euclidian distance as a distance measure. The statistical significance between cluster means was assessed by one-way ANOVA for scale variables, and Kruskal–Wallis tests for ordinal variables.

4. Results and discussion

4.1. Principal component analyses

4.1.1. Principal component analysis of environmental indicators

Based on the results from the PCA of the environmental aspects of vulnerability of farmers, 10 variables resulted in 4 principal components, together explaining 60% of the variance of environmental vulnerability aspects among farmers (Table 3). Based on a KMO value of 0.708 and highly significant Bartlett's test (0.000) the selected set of variables was deemed suitable to proceed with a PCA. Variables with factor loadings greater than 0.6, after a varimax rotation method, are shown in Table 4 and were further considered in the analysis. The first component characterizes the lack of good distribution of rainfall and frost variables, accounting for 17% of the total variance (Table 3). The second component characterizes yellow rust (stripe rust), weeds, heat and hail conditions, and accounts for 16% of the total variance; the third component, which accounts for 14.5% of the total variance, consists of pest and disease variables including bunts (smuts) and sunn pest, and the final component characterizes dry end of season conditions and drought, accounting for 13.25% of the total variance.

Frost is one of the main stressors for wheat. When frost occurs at the reproductive growth stage of wheat, it causes heavy damage to sensitive and susceptible varieties. Generally, about 70% of the wheat production losses within the province are due to damage caused directly by frost (Jalal Kamali et al., 2012). Accordingly, 'Cold stress' is selected as the name of the first component (Table 4). Common biotic stressors of wheat, including yellow rust, weeds, bunts (Smuts) and the sunn pest, emerge as the second component, which is named 'Common biotic stresses'. Heat and hail are other environmental variables that contribute to farmers' vulnerabilities and this component was named 'Climate stresses'. A dry end of season and droughts are variables which load onto the fourth factor. In recent years, farmers in the Khorasan Razavi province have experienced successive droughts due to the irregular distribution of precipitation, which have caused groundwater levels to fall, the only available source of water available for use during the summer. Also the end of the growing season was dry, resulting in water shortages during the wheat's reproductive stage. So, 'Terminal drought' was selected as the component name. The results of PCA depict that frost and bunts (Smuts) are, respectively, the most important abiotic and biotic stressors due to climate change for farmers in the Khorasan Razavi province, confirming results of Jalal Kamali et al. (2012).

Table 3. Extracted factors with eigenvalues and percentages of variance and cumulative variance for environmental indicators (KMO = 0.708).

Component	Eigenvalues	Percentage of variance	Percentage of cumulative variance
1	2.0	17	17
2	1.9	15	32
3	1.7	14	47
4	1.6	13	60

Table 4. Variables related to each component and the coefficients obtained from the matrix.

Component	Variable	Factor loading
1	Lack of good distribution of rainfall	0.605
Cold stress	Frost	0.813
2	Yellow rust (stripe rust)	0.604
Common biotic stresses	Weeds	0.662
	Bunts (Smuts)	0.665
	Sunn pest	0.654
3	Heat	0.741
Climate stresses	Hail	0.699
4	Dry end of season (DES)	0.757
Terminal drought	Drought	0.712

4.1.2. Principal component analysis of socio-economic indicators

The PCA of socio-economic vulnerability aspects of farmers, which includes 23 variables, resulted in 4 principal components with factor loadings greater than 0.6, which together explain 62% of the variance of the socio-economic vulnerability aspects (Tables 5 and 6). After checking a scree plot, only three components (including 19 variables) were extracted for analysis. Together, the three components accounted for 53% of the variance of socio-economic vulnerability aspects (Table 5). The KMO value of 0.922 and significant Bartlett's test (0.000) imply that the set of variables is suitable for PCA. The first component characterizes managerial tips and variables, including: amount of seed, observed crop rotation, cultivated area in relation to resource constraints (water, mechanization and machines), early recognition of characteristics of the season, management of planting date, time of irrigation, date of harvest, proper adjustment of devices and pick-up speed control of drivers, all of which account for 23% of the total variance (Table 5). The second component, which accounts for 18% of the total variance, characterizes supportive government policies including: effectiveness and efficiency of public sector's

Table 5. Extracted factors with eigenvalues and percentages of variance and cumulative variance for socio-economic indicators (KMO = 0.922).

Component	Eigenvalues	Percentage of variance	Percentage of cumulative variance
1	5.5	23	23
2	4.2	18	41
3	3.0	12	53
4	2.2	9	62

Table 6. Variables related to each factor and the coefficients obtained from the matrix.

Component	Variable	Abbreviation	Factor loading
1	Amount of seed	AS	0.66
Management Tips	Observe crop rotation	OCR	0.67
	Cultivated area in relation to resource constraints (Water, mechanization and machines)	CARC	0.70
	Early recognition of characteristics of the season	ERCS	0.69
	Management of planting date	MPD	0.80
	Time of Irrigation	TI	0.83
	Date of harvest	DH	0.68
	Proper adjustment of devices and pick-up speed control of drivers	PDPS	0.81
2	Effectiveness and efficiency of public sector service delivery and seed production	EPSSP	0.74
Supportive government policies (SPO)	Delivery of products, delivery and payment systems (across public sector)	DPS	0.74
	Price stability of crops competing with wheat	PSCW	0.67
	Wheat import policy	WIP	0.73
	Declaring good and acceptable guaranteed prices to farmers based on the international prices	DGPIP	0.71
	Land consolidation policies	LCP	0.75
	Determining the price of wheat before cultivation	DPW	0.72
3	Change variety	CV	0.72
Management of seed and variety	Use of certified seed	UCS	0.83
	Winnowing and disinfected seeds used	WDS	0.65
	Follow guidelines of agricultural Jihad	FGAJ	0.67
4	Energy prices (machinery fuel, diesel, electricity)		0.73
Cost of production	Cost of fertilizer per hectare		0.73
	Cost of machineries and equipment and their repair costs		0.73
	Cost of water per hectare		0.67

involvement in service delivery and seed production, delivery of products, delivery and payment systems (across public sector), price stability of crops competing with wheat, wheat import policies, declaring good and acceptable guaranteed prices to farmers based on international prices, land consolidation policies and determining the price of wheat before cultivation. The third component, which accounts for 12% of the total variance, consists of variables pertaining to seed management and variety, including: changing variety, use of certified seed, winnowing and use of disinfected seeds, and following the guidelines of agricultural Jihad. The final component characterizes the cost of production, including: energy prices (machinery fuel, diesel, and electricity), the cost of fertilizer per hectare, the cost of machineries and equipment and their repair costs, and the cost of water per hectare. This component accounts for 9% of the total variance.

Results on the consequences of socio-economic vulnerability aspects to farmers' households concur with previous studies (Feng et al., 2007; Khoshnodifar et al., 2012; Lobell et al., 2002; Luers et al., 2003; Rurinda et al., 2014; Yang et al., 2007). These studies attribute a key role to changes in management in determining impact on production of any changes in the climate. In this regard, the Iranian representative of the International Maize and Wheat Improvement Centre, argues that 'If farmers select suitable varieties and observe crop rotation, spraying will not be needed, as weeds are being better managed'. Also, Zarafshani et al. (2012) and Khoshnodifar et al. (2012) report that Iranian wheat farmers' vulnerability is mainly influenced by socio-economic factors. One of the wheat farmers participating in this study expressed that 'When environmental conditions are not conducive through extreme events, the choice of less sensitive varieties and adjustment of available water to the cultivated area are very important strategies for every farmer and they should not anticipate high yields' (Professional wheat farmer in Taiebad, 47 years old and 20 years' experience).

Finally, the most important variables of vulnerability in the study area were identified in order to complete the third ring of VSD (Figure 3).

4.2. Cluster analysis

Three vulnerability clusters are identified (Tables A1–A2). There is a significant difference between Cluster 1 and Cluster 2, although, the largest difference exists between Cluster 2 and 3. The difference between Cluster 1 and Cluster 3 is less pronounced (Figure 4). Although Cluster 1 occupies an overall intermediate position in terms of vulnerability, it differs from the two others in a number of variables, including the income from agricultural products, cultivated area in relation to resource constraints (water, mechanization and machines), and management of planting date. Farmers categorized in Cluster 2 depict the lowest vulnerability to socio-economic terms but are more vulnerable regarding environmental aspects. Farmers classified in Cluster 3 are more vulnerable in socio-economic terms yet show the lowest vulnerability according to environmental aspects (Figure 4). The most severe socio-economic aspect of vulnerability for Cluster 3 is the lack of supportive government policies, such as wheat import policy, declaring good and acceptable guaranteed prices, and determining the price of wheat before cultivation.

Clusters differ significantly in the total cultivated area, cultivation area of irrigated wheat, yield, income from agricultural products, own consumption, market sales, second job and labour. In contrast, farmers' age, work experience, non-agricultural income, income from wheat, education and the number of parcels of agricultural land are not significantly different between the clusters. Table 7 and A2, and Figure 5 present the characteristics of farmers in each of the clusters, showing only the attributes that differ significantly amongst them.

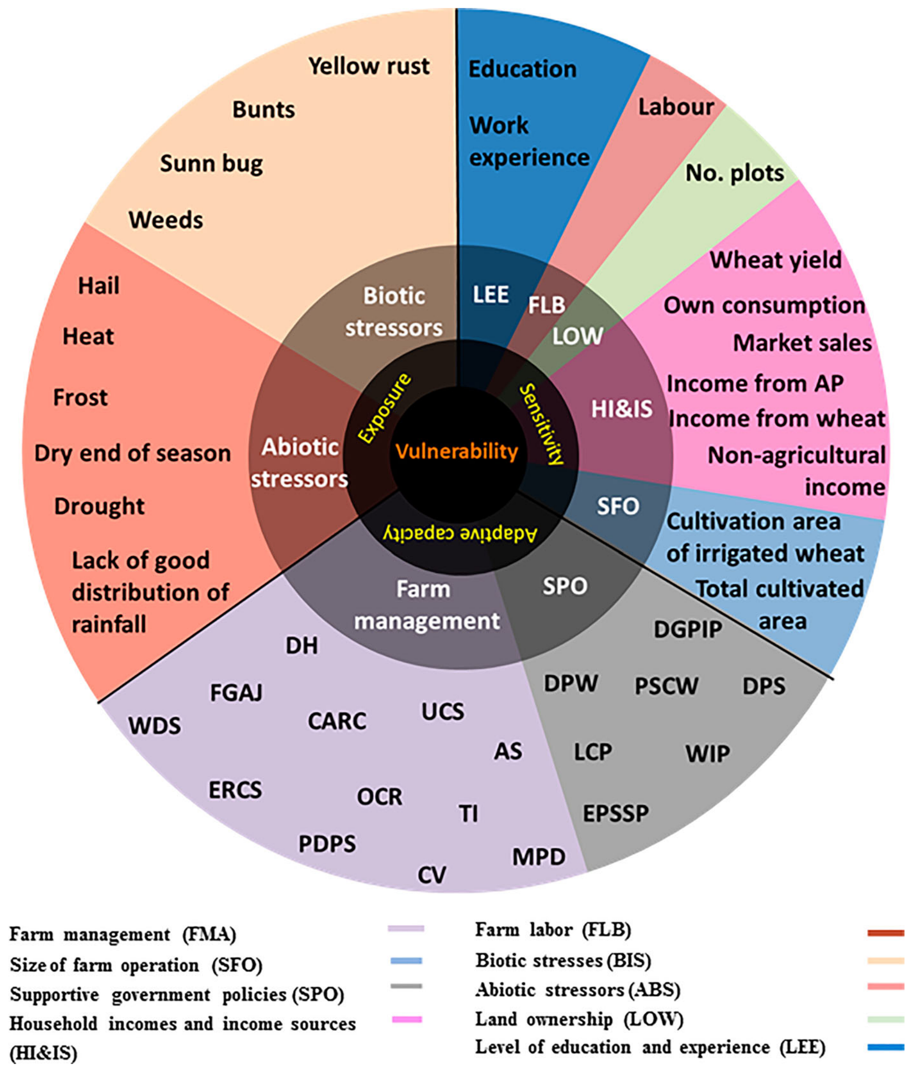

Figure 3. Vulnerability Scoping Diagram for the indicators of wheat farmer's vulnerability. In the inner ring of the VSD there are the three dimensions of vulnerability. In the middle ring each dimension is translated into components making up the environmental or socio-economic context, and each component is operationalized in measures in the outer ring, which indicates how vulnerability could be assessed. For meaning of abbreviations see Table 6.

In Cluster 1, 66% of farmers have a second job and labour is mostly provided by their families. Also, 74% of wheat production is sold to the market in this cluster. Although farmers in Cluster 2 have the largest areas of cultivated crops, income from agricultural products and income from irrigated wheat is lower than in Cluster 1. However, the yield of irrigated wheat is higher than in the other clusters. Additionally, 53% of farmers in this cluster have a second job and most of their labour is provided by their families. In this cluster, 85% of irrigated wheat production is sold to the market. Although about 90% of farmers in Cluster 3 have a second job, they have the lowest area of cultivated crops, irrigated cultivated area, and yield of irrigated wheat and income from agricultural products. In addition, most of their labour force is jointly provided and maintained by their families and local labourers, and 79% of wheat production is sold to the market.

The results from the cluster analysis show that one of the major climate-related risks is drought, especially for the second cluster, which is most vulnerable to drought. Several studies (Keshavarz & Karami, 2016; Keshavarz, Karami, & Vanclay, 2013; Zarafshani et al., 2012) have noted that the main stressor of climate change for farmers was drought. So, to tackle these challenges, they should use resistant varieties of crops that are compatible with the area as recommended by Ahumada-Cervantes et al. (2017), for example those that are introduced annually by the International Maize and Wheat Improvement Centre. Another way to reduce environmental aspects of vulnerability is to disinfect seeds.

The results of cluster analysis and the findings that resulted from similar studies (Chavas, 2001; Deressa, 2010; Keshavarz & Karami, 2013) confirm that government support plays a significant role in improving the adaptive capacity of farmers. Table 8 shows the top-10 vulnerability indicators perceived by farmers in each cluster. The first observation that can be made is that farmers classified in Cluster 3 attributed far greater importance to vulnerability indicators than farmers in the other two clusters. Overall, however, policy-related issues strongly featured in the top-10 for all three clusters. In contrast to our analysis that shows drought as the most important environmental vulnerability factor in Cluster 3, drought is not included in this list.

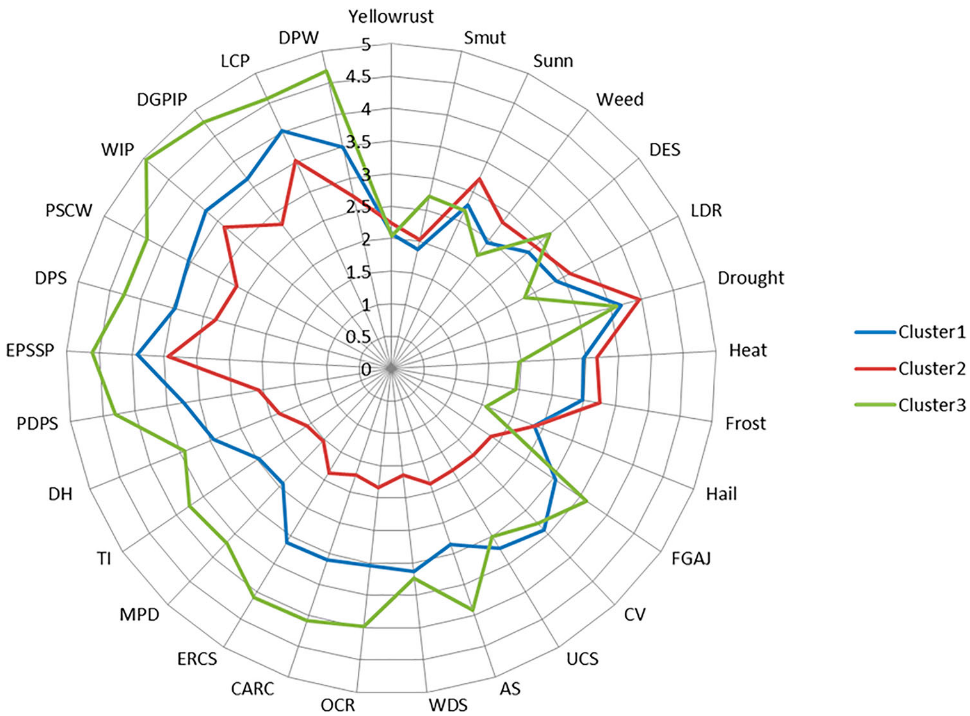

Figure 4. Vulnerability patterns in Khorasan Razavi Province, Iran (for meaning of abbreviations see Table 6) *Scoring pattern: very low damage = 1, low damage = 2, medium damage = 3, high damage = 4 and very high damage = 5.

Table 7. Descriptive statistics of wheat farmers' characteristic (mean, Kruskal-Wallis test) in each of the vulnerability types.

	Vulnerability types of wheat farmers							
	Cluster 1		Cluster 2		Cluster 3			
Characteristic	%		%		%		Chi-square	Sig
Second job	Yes	No	Yes	No	Yes	No	53.2	0.000**
	66	34	53	47	90	10		
	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation		
Number of parcels of agricultural land	3	2.2	3	2	3	1.8	0.2	0.88

Land consolidation is the main problem indicated by farmers categorized in Cluster 1, and it also features highly (2nd and 5th) for farmers in Cluster 2 and 3, respectively.

For Cluster 3, the wheat import policy is the key problem (and it features 3rd and 4th for Cluster 1 and 2 respectively). Developing supportive government policies can reduce the vulnerability of wheat farmers; for example, policies should consider when and at which price they have to import wheat to the country, so that domestic wheat farmers are not affected. For instance, when farmers harvest their wheat, the government should not import wheat at prices lower than the domestic price. Especially farmers grouped in Cluster 3 highlighted the lack of guaranteed and early-announced prices as factors that contribute to their vulnerability. If the government declares acceptable guaranteed prices for farmers based on the international market price before cropping, not only it will cover the costs of farmers but in turn, growing wheat will also become profitable for them. There are other policies that can alleviate the vulnerability of the most vulnerable farmers. For example, through the public sector's involvement in service delivery and seed production by providing a timely and adequate supply of certified seed. Additionally, the government could, by providing public sector presence in the regions, coordinate and mobilize farmers to control the sunn pest, weeds and so forth, as their control requires the collaboration of all farmers. Farmers in the first and third cluster have had the highest managerial damage because they do not consider some important management tips – for example they do not properly adjust devices and do not control the pick-up speed of drivers. This can reduce the accuracy of the harvesting (leaving behind grains with crop residues on the ground) or may reduce the effect of weed management.

As Table 8 shows, changing the wheat varieties grown and early recognition of characteristics of the season are important factors for farmers because they can use these technological advances to cope with adverse climate change, biotic and abiotic stressors. Overall, farmers in Cluster 2 have a better socio-economic situation and are better performers. Government policies may be more efficient for farmers in the second cluster, but on the other hand, farmers in this cluster, compared to other clusters, observe better farm management practices although they are exposed to more environmental vulnerability aspects than other clusters. In the third cluster, wheat farmers are less exposed to environmental vulnerability aspects but because of that, they have less considerate management

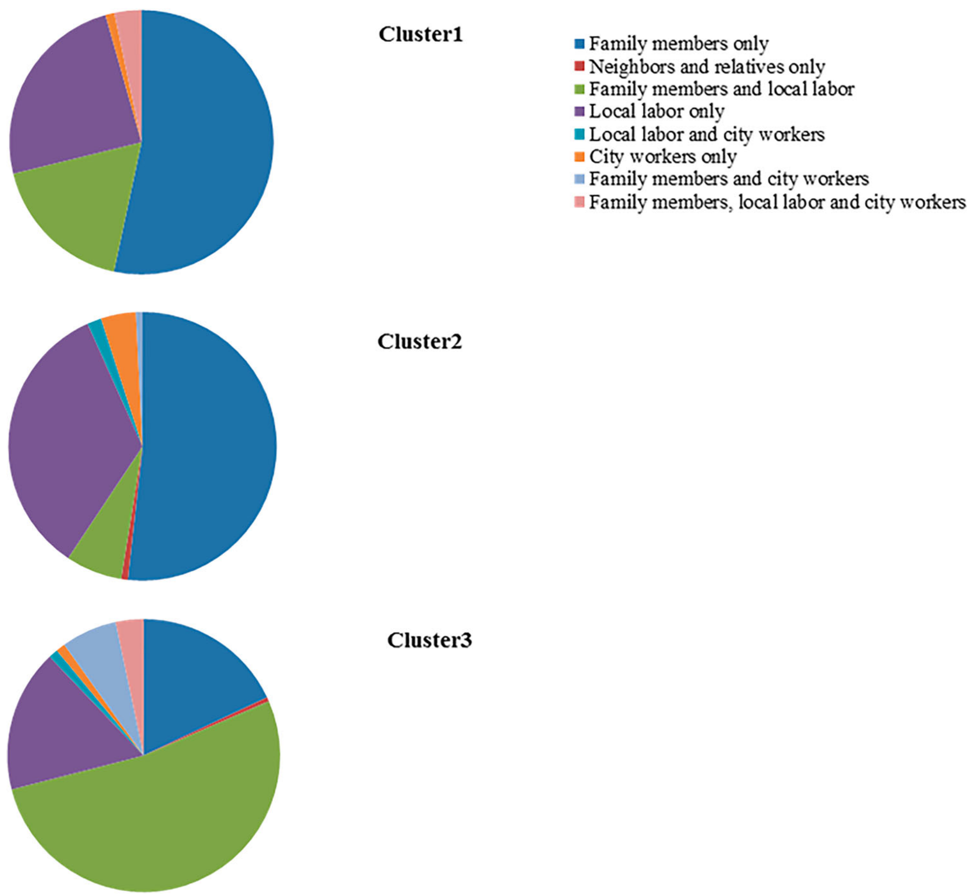

Figure 5. Composition of wheat farmers' labour in each of the vulnerability types.

Table 8. Top-10 vulnerability indicators and scores for each cluster according to farmers' perception. Colours match the vulnerability dimensions of Figure 3.

	Cluster 1		Cluster 2		Cluster 3	
Row	Vulnerability Indicator	Score	Vulnerability Indicator	Score	Vulnerability Indicator	Score
1	Land consolidation policies	4.03	Drought	3.95*	Wheat import policy	4.96*
2	Effectiveness and efficiency of public sector's involvement in service delivery and seed	3.91	Land consolidation policies	3.52	Declaring good and acceptable guaranteed prices to farmers	4.76*
3	Wheat import policy	3.74	Effectiveness and efficiency of public sector's involvement in service delivery and seed	3.44	Determining the price of wheat before cultivation	4.68*
4	Drought	3.67	Wheat import policy	3.37	Effectiveness and efficiency of public sector's involvement in service delivery and seed	4.63*
5	Declaring good and acceptable guaranteed prices to farmers	3.67	Frost	3.25*	Land consolidation policies	4.57*
6	Price stability of crops competing with wheat	3.54	Sunn pest	3.22*	Proper adjustment of devices and pick-up speed control of drivers	4.31*
7	Determining the price of wheat before cultivation	3.48	Heat	3.16*	Delivery of products, delivery and payment systems	4.27*
8	Delivery of products, delivery and payment systems	3.45	Lack of good distribution of rainfall	3.11*	Price stability of crops competing with wheat	4.26*
9	Change variety	3.28	Dry end of season	2.9	Early recognition of characteristics of the season	4.11*
10	Proper adjustment of devices and pick-up speed control of drivers	3.24	Weeds	2.83*	Cultivated area in relation to resource constraints	4.08*

*Highest vulnerability score for this indicator across clusters.

practices as well. It is possible that government programmes are not effective enough for this cluster and as a result their vulnerability is more severe. However, this cluster includes a large number of farmers. As a result, decision-makers and policy-makers must make serious decisions to help farmers in the third cluster adapt, particularly in overcoming socio-economic vulnerabilities they face. Although this also applies to farmers in the first cluster, they may be able to cope better with adverse environmental conditions because they observe better farm management practices.

6. Conclusions

This study presents a typology of farmers' vulnerability of wheat smallholder farmers in Northeast Iran based on a factor analysis and clustering of socio-ecological indicators obtained from a farm household survey. Utilizing these techniques helps to highlight key combinations of socio-economic and environmental determinants of vulnerability, and to assess similarities and differences in wheat farmers' vulnerability. Three clusters of vulnerability were distinguished.

Almost half (47%) of the sampled farmers belong to Cluster 3, which have the lowest area of cultivated crops, irrigated cultivated area, yield of irrigated wheat and income from agricultural products. Ninety percent of Cluster 3 farmers have a second job, and they featured highest levels of vulnerability scores. They perceive socio-economic factors as key determinant of their vulnerability, in particular the government's wheat import policy, failure to declare good and acceptable guaranteed prices, and determine the price of wheat before cultivation. They moreover also report vulnerabilities from suboptimal farm management.

A smaller share (23%) of farmers belong to Cluster 1 with intermediate vulnerability. They particularly differ from other clusters in terms of income from agricultural products, cultivated area in relation to resource constraints (water, mechanization and machines), and management of planting date. Their main vulnerability factor is lack of land consolidation, and other policy-related issues such as limited effectiveness and efficiency of public sector's involvement in service delivery and seed supply. Drought and farm management deficiencies affect them as well.

Finally, 30% of farmers belong to Cluster 2. This cluster has the largest area of cultivated crops and highest income from agricultural products and highest yield of irrigated wheat, although the area of irrigated wheat is lower than in Cluster 1. These farmers have a stronger focus on agriculture, and only 53% has a second job. This cluster has the lowest vulnerability in socio-economic terms, but is more vulnerable regarding environmental aspects, especially drought. They perceive limited options for improved farm management.

This typology of farmers' vulnerability offers valuable guidance to policymakers and decision-makers to reduce vulnerability of wheat farmers. The Iranian government should adopt differentiated policies to reduce the vulnerability of wheat farmers. Above all, supportive governmental policies could improve socio-economic vulnerability aspects, although accents differ per cluster. For Cluster 1, land consolidation is key, whereas for Cluster 3 changes in wheat import policy, to avoid negative effects for domestic wheat farmers, and pricing policy, offering guaranteed prices for farmers based on the international market price before cropping is the first priority. Government action to support collaborative control of sunn pest and weeds would benefit Cluster 2 farmers. Whereas Cluster 2 farmers can manage farms effectively, Clusters 1 and particularly 3 would also benefit from farm advisory services to reduce their vulnerability.

For farmers who largely depend on irrigated wheat cultivation, combined consideration of supportive governmental policies and improved management can result in the reduction of environmental vulnerability aspects. Increasing drought frequency associated with future climate change may cause worsening of water scarcity and require further adjustments in wheat management.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Saeedeh Nazari Nooghabi holds a PhD in Agricultural Extension and Education and has participated in different scientific disciplines including social science, land management and environmental departments. She is familiar with decision support systems and modelling socio-economic aspects of climate change and environmental impact assessment, mixed-method approaches including quantitative and qualitative techniques and their software. She is currently working as a supervisor at Persian Daroo-e-Alborz Research and Technology Fund Institute, Tehran to develop and support high-tech businesses in the field of agricultural and food industries.

Luuk Fleskens is associate professor at the Soil Physics and Land Management Group, Wageningen University, The Netherlands, with expertise in impact assessment of land management. His research focuses on how land and water management interventions can increase resilience of agro-ecosystems. He uses integrated environmental models and participatory methods to assess the impact of environmental change and the effects of adaptation and mitigation strategies on rural livelihoods and ecosystem services. Strategies thereby include both farmer management practices and policies, and impacts are assessed in both physical and economic terms, at different scales, and taking into account diverging socio-cultural perceptions of various stakeholders.

Diana Sietz is a Senior Researcher in the Working Groups 'Ecosystem Stability and Transitions' and 'Hydroclimatic Risks' at Potsdam Institute for Climate Impact Research, Germany. Diana conducts and leads research that aims to better understand key interlinkages between land use, climate and biodiversity and the transfer of successful adaptive strategies. She is interested in the interactions between natural resources and livelihood strategies at local, regional and global scales. Archetypical patterns in underlying processes, critical thresholds and catastrophic shifts in social-ecological systems receive specific attention. She coordinates the Working Group on 'Archetype Analysis in Sustainability and Land Governance Research' at Future Earth's Global Land Programme. She is also an Editor of Regional Environmental Change Journal.

Hossein Azadi is a senior scientific staff at Department of Geography, Ghent University in Belgium and Research Group Climate Change and Security, University of Hamburg in Germany. He is also an adjunct professor at the Faculty of Environmental Science and Engineering, Babes-Bolyai University in Romania and a guest professor at Mekelle University in Ethiopia. He was also a Fulbright fellow at the State University of New York at Binghamton. During his academic career, he applied a variety of mixed methods on the socio-economic impact assessments of sustainable agri-rural development projects.

ORCID

Saeedeh Nazari Nooghabi http://orcid.org/0000-0003-1760-257X
Luuk Fleskens http://orcid.org/0000-0001-6843-0910
Diana Sietz http://orcid.org/0000-0002-2309-2134
Hossein Azadi http://orcid.org/0000-0002-5108-1993

References

Acosta-Michlik, L., & Espaldon, V. (2008). Assessing vulnerability of selected farming communities in the Philippines based on a behavioral model of agent's adaptation to global environmental change. *Global*

Environmental Change, *18*, 554–563. doi:10.1016/j.gloenvcha.2008.08.006

Adejuwon, J. (2008). Vulnerability in Nigeria: A national-level assessment. In N. Leary, C. Conde, A. Nyong, & J. Pulhin (Eds.), *Climate change and vulnerability* (pp. 198–217). London: Earthscan Publications Ltd.

Ahumada-Cervantes, R., Velázquez-Angulo, G., Rodríguez-Gallegos, H. B., Flores-Tavizón, E., Félix-Gastélum, R., Romero-González, J., & Granados-Olivas, A. (2017). An indicator tool for assessing local vulnerability to climate change in the Mexican agricultural sector. *Mitigation and Adaptation Strategies for Global Change*, *22*, 137–152. doi:10.1007/s11027-015-9670-z

Aleksandrova, M., Gin, A. K., & Giupponi, C. (2016). Assessing agricultural systems vulnerability to climate change to inform adaptation planning: An application in Khorezm, Uzbekistan. *Mitigation and Adaptation Strategies for Global Change*, *21*, 1263–1287. doi:10.1007/s11027-015-9655-y

Amid, J. (2007). The dilemma of cheap food and self-sufficiency: The case of wheat in Iran. *Food Policy*, *32*, 537–552. doi:10.1016/j.foodpol.2006.11.001

Birkmann, J. (2006). Measuring vulnerability to promote disaster-resilient societies: Conceptual frameworks and definitions. In J. Birkmann (Ed.), *Measuring vulnerability to natural hazards – towards disaster resilient societies* (pp. 9–54). Tokyo: United Nations University Press.

Brooks, N., Adger, W. N., & Kelly, P. M. (2005). The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change*, *15*, 151–163.

Chavas, J. P. (2001). Chapter 5 Structural change in agricultural production: Economics, technology and policy. In B. L. Gardner & G. C. Rausser (Eds.), *Handbook of agricultural economics* (vol. 1, Part A, pp. 263–285). Amsterdam: Elsevier.

Cochran, W. G. (1977). *Sampling techniques* (3rd ed.). London: John Wiley & Sons.

Coletti, A., Howe, P. D., Yarnal, B., & Wood, N. J. (2013). A support system for assessing local vulnerability to weather and climate. *Natural Hazards*, *65*, 999–1008. doi:10.1007/s11069-012-0366-3

Cutter, S. L., & Finch, C. (2008). Temporal and spatial changes in social vulnerability to natural hazards. *Proceedings of the National Academy of Sciences*, *105*(7), 2301–2306. doi:10.1073/pnas.0710375105

Dabi, D. D., Nyong, A. O., Adpetu, A. A., & Ihemegbulem, V. I. (2008). Past, present and future adaptation by rural households of Northern Nigeria. In N. Leary, J. Adejuwon, V. Barros, I. Burton, J. Kulkarni, & R. Lasco, *Climate change vulnerability* (pp. 147–160). London: Earthscan Publications Ltd.[?]

Deihimfard, R., Zand, E., Mahdavi Damghani, A., & Soufizadeh, S. (2007). Herbicide risk assessment during the wheat self-sufficiency project in Iran. *Pest Management Science*, *63*(10), 1036–1045. doi:10.1002/ps.1432

Deininger, K., & Feder, G. (2001). Chapter 6 Land institutions and land markets. In B. L. Gardner & G. C. Rausser (Eds.), *Handbook of agricultural economics* (Vol. 1, Part A, pp. 287–331). Amsterdam: Elsevier.

Deressa, T. T. (2010). *Assessment of the vulnerability of Ethiopian agriculture to climate change and farmers' adaptation strategies* (Doctoral dissertation, University of Pretoria, Pretoria, South Africa). Retrieved from http://upetd.up.ac.za/thesis/available/etd-10232010-165854/unrestricted/thesis.pdf

Dunford, R., Harrison, P. A., Jager, J., Rounsevell, M. D. A., & Tinch, R. (2015). Exploring climate change vulnerability across sectors and scenarios using indicators of impacts and coping capacity. *Climatic Change*, *128*, 339–354. doi:10.1007/s10584-014-1162-8

Eakin, H., Webhe, M., Ávila, C., Sánchez Torres, G., & Bojórquez-Tapia, L. A. (2006). *A Comparison of the social vulnerability of grain farmers in Mexico and Argentina* (AIACC Working Paper 29). Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.631.2581&rep=rep1&type=pdf

Faramarzi, M., Yang, H., Schulin, R., & Abbaspour, K. C. (2010). Modelling wheat yield and crop water productivity in Iran: Implications of agricultural water management for wheat production. *Agricultural Water Management*, *97*, 1861–1875. doi:10.1016/j.agwat.2010.07.002

Feng, L., Bouman, B. A. M., Tuong, T. P., Cabangon, R. J., Li, Y., Lu, G., & Feng, Y. (2007). Exploring options to grow rice using less water in northern China using a modelling approach: I. Field experiments and model evaluation. *Agricultural Water Management*, *88*, 1–13. doi:10.1016/j.agwat.2006.10.006

Füssel, H. M. (2007). Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change*, *17*, 155–167. doi:10.1016/j.gloenvcha.2006.05.002

Harvey, C. A., Chacon, M., Donatti, C. I., Garen, E., Hannah, L., Andrade, A., … Wollenberg, E. (2013). Climate-smart landscapes: Opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. *Conservation Letters*, *7*, 77–90. doi:10.1111/conl.12066

Hinkel, J. (2011). "Indicators of vulnerability and adaptive capacity": Towards a clarification of the science–policy interface. *Global Environmental Change*, *21*, 198–208. doi:10.1016/j.gloenvcha.2010.08.002

Huffman, W. E. (2001). Chapter 7 human capital: Education and agriculture. In B. L. Gardner & G. C. Rausser (Eds.), *Handbook of agricultural economics* (Vol. 1, Part A, pp. 333–381). Amsterdam: Elsevier.

IPCC. (2007). Summary for policymakers. In J. Palutikof, P. van der Linden, & C. Hanson (Eds.), *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change* (pp. 7–22). Cambridge: Cambridge University Press.

Iranian Agricultural Ministry, Khorasan Agricultural Research Center. (1997). *Dual use of cereals* (wheat, barley, triticale, corn, rice). Second volume.

Iranian Statistics Centre. (2012). *National statistics year book*. Tehran: Iranian Statistics Centre.

Iranian Statistics Centre. (2015). *Agricultural statistic book*. Tehran: Iranian Statistics Centre.

Jäger, J., Kok, M., Mohamed-Katerere, J. C., Karlsson, S. I., Ludeke, M. K. B., Dabelko, G. D., … Sietz, D. (2007). Vulnerability of people and the environment: Challenges and opportunities. In *Global environment Outlook 4: Environment for development* (pp. 301–360). Nairobi: UNEP.

Jalal Kamali, M. R., NajafiMirak, T., & Asadi, H. (2012). *Wheat research and development strategies in Iran*. Tehran: Agricultural Research, Education and Extension Organization.

Jiao, X., & Moinuddin, H. (2016). Operationalizing analysis of micro-level climate change vulnerability and adaptive capacity. *Climate and Development*, *8*(1), 45–57. doi:10.1080/17565529.2014.989191

Kappes, M. S., Papathoma-Kohle, M., & Keiler, M. (2012). Assessing physical vulnerability for multi-hazards using an indicator-based methodology. *Applied Geography*, *32*, 577–590. doi:10.1016/j.apgeog.2011.07.002

Keshavarz, M., & Karami, E. (2013). Institutional adaptation to drought: The case of Fars agricultural Organization. *Journal of Environmental Management*, *127*, 61–68. doi:10.1016/j.jenvman.2013.04.032

Keshavarz, M., & Karami, E. (2016). Farmers' pro-environmental behaviour under drought: Application of protection motivation theory. *Journal of Arid Environments*, *127*, 128–136. doi:10.1016/j.jaridenv.2015.11.010

Keshavarz, M., Karami, E., & Vanclay, F. (2013). The social experience of drought in rural Iran. *Land Use Policy*, *30*, 120–129. doi:10.1016/j.landusepol.2012.03.003

Keshavarz, M., Maleksaeidi, H., & Karami, E. (2017). Livelihood vulnerability to drought: A case of rural Iran. *International Journal of Disaster Risk Reduction*, *21*, 223–230. doi:10.1016/j.ijdrr.2016.12.012

Khan, S. (2012). Vulnerability assessments and their planning implications: A case study of the Hutt Valley, New Zealand. *Natural Hazards*, *64*, 1587–1607. doi:10.1007/s11069-012-0327-x

Khazai, B., Merz, M., Schulz, C., & Borst, D. (2013). An integrated indicator framework for spatial assessment of industrial and social vulnerability to indirect disaster losses. *Natural Hazards*, *67*, 145–167. doi:10.1007/s11069-013-0551-z

Khoshnodifar, Z., Sookhtanlo, M., & Gholami, H. (2012). Identification and measurement of indicators of drought vulnerability among wheat farmers in Mashhad County, Iran. *Scholars Research Library Annals of Biological Research*, *3*(9), 4593–4600.

Kok, M., Ludeke, M., Lucas, P., Sterzel, T., Walther, C., Janssen, P., … Soysa, I. D. (2016). A new method for analysing socio-ecological patterns of vulnerability. *Regional Environmental Change*, *16*(1), 229–243. doi:10.1007/s10113-014-0746-1

Lavorel, S., Colloff, M. J., McIntyre, S., Doherty, M. D., Murphy, H. T., Metcalfe, D. J., … Williams, K. J. (2015). Ecological mechanisms underpinning climate adaptation services. *Global Change Biology*, *21*, 12–31. doi:10.1111/gcb.12689

Lebel, S., Fleskens, L., Forster, P. M., Jackson, L. S., & Lorenz, S. (2015). Evaluation of in situ rainwater harvesting as an adaptation strategy to climate change for maize production in rainfed Africa. *Water Resources Management*, *29*(13), 4803–4816. doi:10.1007/s11269-015-1091-y

Leichenko, R. M., & O'Brien, K. L. (2002). The dynamics of rural vulnerability to global change: The case of Southern Africa. *Mitigation and Adaptation Strategies for Global Change*, *7*, 1–18. doi:10.1023/A:1015860421954

Lobell, D. B., Ortiz-Monasterio, J. I., Addams, C. L., & Asner, G. P. (2002). Soil, climate and management impacts on regional wheat productivity in Mexico from remote sensing. *Agricultural and Forest Meteorology*, *114*, 31–43.

Luers, A. L., Lobell, D. B., Sklar, L. S., Addams, C. L., & Matson, P. A. (2003). A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico. *Global Environmental Change*, *13*(4), 255–267.

McCarthy, J. J., Canziani, O. K., Leary, N. A., Dokken, D. J., & White, K. S. (2001). Impacts, Adaptation and vulnerability. *Third Assessment Report of the Intergovernmental panel on climate change*, *Working Group 2*.

Navarra, A., & Tubiana, L. (2013). *Regional assessment of climate change in the Mediterranean Volume 3: Case studies*. New York, NY: Springer.

Nazari, N., Pezeshki Rad, G., Sedighi, H., & Azadi, H. (2015). Vulnerability of wheat farmers: Toward a conceptual framework. *Ecological Indicators*, *52*, 517–532. doi:10.1016/j.ecolind.2015.01.006

Oberlack, C., Sietz, D., de Bremond, A., Bürgi-Bonanomi, E., Dell'Angelo, J., Eisenack, K., … Villamayor-Tomás, S. (2019). Archetype analysis in sustainability research: Meanings, motivations, and evidence-based policy-making. *Ecology and Society*, *24*(2), 26. doi:10.5751/ES-10747-240226

Osman-Elasha, B., & Sanjak, E. A. (2008). Livelihoods and drought in Sudan. In N. Leary, C. Conde, A. Nyong, & J. Pulhin (Eds.), *Climate change and vulnerability* (pp. 239–254). London: Earthscan Publications Ltd.

Paavola, J. (2008). Livelihood, vulnerability and adaptation to climate change in Morogoro, Tanzania. *Environmental Science and Policy*, *11*, 642–654. doi:10.1016/j.envsci.2008.06.002

Panda, A. (2016). Vulnerability to climate variability and drought among small and marginal farmers: A case study in Odisha, India. *Climate and Development*, *9*, 605–617. doi:10.1080/17565529.2016.1184606

Polsky, C., Neff, R., & Yarnal, B. (2007). Building comparable global change vulnerability assessments: The vulnerability scoping diagram. *Global Environmental Change*, *17*, 472–485. doi:10.1016/j.gloenvcha.2007.01.005

Rajesh, S., Jain, S., Sharma, P., & Bhahuguna, R. (2014). Assessment of inherent vulnerability of rural communities to environmental hazards in Kimsar region of Uttarakhand, India. *Environmental Development*, *12*, 16–36. doi:10.1016/j.envdev.2014.06.003

Reidsma, P. (2007). *Adaptation to climate change: European agriculture* (Doctoral dissertation). Wageningen University, Wageningen, the Netherlands. Retrieved from http://library.wur.nl/WebQuery/wurpubs/fulltext/121920

Reidsma, P., & Ewert, F. (2008). Regional farm diversity can reduce vulnerability of food production to climate change. *Ecology and Society*, *13*(1), 38. http://www.ecologyandsociety.org/vol13/iss1/art38/

Rurinda, J., Mapfumo, P., Van Wijk, M. T., Mtambanengwe, F., Rufino, M. C., Chikowo, R., & Giller, K. E. (2014). Sources of vulnerability to a variable and changing climate among smallholder households in Zimbabwe: A participatory analysis. *Climate Risk Management*, *3*, 65–78. doi:10.1016/j.crm.2014.05.004

Sahu, M., Dehury, B., Kumar Modi, M., & Barooah, M. (2014). Functional genomics and bioinformatics approach to understand regulation of abiotic stress in cereal crops. In R. Roychowdhury (Ed.), *Crop improvement in the era of climate change* (p. 205). Delhi: International Publishing House Pvt. Ltd.

Sangpenchan, R. (2011). *Vulnerability of Thai rice production to simultaneous climate and socioeconomic change: A double exposure analysis* (Doctoral dissertation) (p. 205). The Pennsylvania State University, PA.

Shrestha, S. L. (2011). *Effect of climate change on socio-economy and vulnerability of farmers in Nepal* (Master's Thesis). Hiroshima University, Hiroshima, Japan.

Sietz, D. (2014). Regionalisation of global insights into dryland vulnerability: Better reflecting smallholders' vulnerability in Northeast Brazil. *Global Environmental Change*, *25*(1), 173–185. doi:10.1016/j.gloenvcha.2014.01.010

Sietz, D., Frey, U., Roggero, M., Gong, Y., Magliocca, N., Tan, R., & Václavík, T. (2019). Archetype analysis in sustainability research: Methodological portfolio and analytical frontiers. *Ecology and Society*, *24*(3), 34. doi:10.5751/ES-11103-240334

Sietz, D., Ludeke, M. K. B., & Walther, C. (2011). Categorization of typical vulnerability patterns in global drylands. *Global Environmental Change*, *21*, 431–440. doi:10.1016/j.gloenvcha.2010.11.005

Sietz, D., Ordoñez, J. C., Kok, M. T. J., Janssen, P., Hilderink, H. B., Tittonell, P., & van Dijk, H. (2017). Nested archetypes of vulnerability in African drylands: Where lies potential for sustainable agricultural intensification? *Environmental Research Letters*, *12*(9), 095006.

Simelton, E., Fraser, E. D. C., Termansen, M., Forster, P. M., & Dougill, A. J. (2009). Typologies of crop-drought vulnerability: An empirical analysis of the socio-economic factors that influence the sensitivity and resilience to drought of three major food crops in China (1961–2001). *Environmental Science and Policy*, *12*, 438–452. doi:10.1016/j.envsci.2008.11.005

Spinoni, J., Naumann, G., & Vogt, J. V. (2017). Pan-European seasonal trends and recent changes of drought frequency and severity. *Global and Planetary Change*, *148*, 113–130. doi:10.1016/j.gloplacha.2016.11.013

Sterzel, T., Lüdeke, M. K. B., Walther, C., Kok, M. T., … Lucas, P. L. (in press). Global typology of coastal urban vulnerability under rapid urbanization. *Plos One*, in press.

Tate, E. (2012). Social vulnerability indices: A comparative assessment using uncertainty and sensitivity analysis. *Natural Hazards*, *63*, 325–347. doi:10.1007/s11069-012-0152-2

Tuler, S. P., Webler, T., & Polsky, C. (2013). A rapid impact and vulnerability assessment approach for commercial fisheries management. *Ocean and Coastal Management*, *71*, 131–140. doi:10.1016/j.ocecoaman.2012.09.013

Vignola, R., Harvey, C. A., Bautista-Solis, P., Avelino, J., Rapidel, B., Donatti, C., & Martinez, R. (2015). Ecosystem-based adaptation for smallholder farmers: Definitions, opportunities and constraints. *Agriculture, Ecosystems and Environment*, *211*, 126–132. doi:10.1016/j.agee.2015.05.013

Wang, Y., & Frei, M. (2011). Stressed food – The impact of abiotic environmental stresses on crop quality. *Agriculture, Ecosystems and Environment*, *141*, 271–286. doi:10.1016/j.agee.2011.03.017

Wolf, T., & McGregor, G. (2013). The development of a heat wave vulnerability index for London, United Kingdom. *Weather and Climate Extremes*, *1*, 59–68. doi:10.1016/j.wace.2013.07.004

Xiao, D., Moiwo, J. P., Tao, F., Yang, Y., Shen, Y., Xu, Q., … Liu, F. (2015). Spatiotemporal variability of winter wheat phenology in response to weather and climate variability in China. *Mitigation and Adaptation Strategies for Global Change*, *20*, 1191–1202. doi:10.1007/s11027-013-9531-6

Yang, X., Lin, E., Ma, S., Ju, H., Guo, L., Xiong, W., & Xu, Y. (2007). Adaptation of agriculture to warming in Northeast China. *Climatic Change*, *84*(1), 45. doi:10.1007/s10584-007-9265-0

Yingchun, L., Xiong, W., Hu, W., Berry, P., Ju, H., Lin, E., … Pan, J. (2015). Integrated assessment of China's agricultural vulnerability to climate change: A multi-indicator approach. *Climatic Change*, *128*, 355–366. doi:10.1007/s10584-014-1165-5

Zarafshani, K., Sharafi, L., Azadi, H., Hosseininia, G., De Maeyer, P., & Frank, W. (2012). Drought vulnerability assessment: The case of wheat farmers in Western Iran. *Global and Planetary Change*, *98–99*, 122–130. doi:10.1016/j.gloplacha.2012.08.012

Zarefiezabadi, A., Sharifi, H., & Beheshti, A. (2003). *Analysis of the production and purchase of wheat in Khorasan Razavi province*. Tehran: Iranian Agricultural Ministry, Agricultural Research, Education and Extension Organization, Khorasan Agricultural Research.

Appendix

Table A1. Descriptive statistics of wheat farmers' environmental and socio-economic variables (mean, Kruskal-Wallis test) in each of the vulnerability types.

		Cluster 1 ($n = 90$)		Cluster 2 ($n = 118$)		Cluster 3 ($n = 183$)				
		Patterns of environmental vulnerability aspects of wheat farmers								
Indicator	Environmental variables	Mean*	Std. Deviation	Mean*	Std. Deviation	Mean*	Std. Deviation	Average*	Chi-square	Sig
Cold stress	Lack of good distribution of rainfall	2.88	1.30	3.11	1.43	2.32	0.91	2.77	25.80	0.000**
	Frost	2.98	1.35	3.25	1.46	1.94	0.85	2.72	70.84	0.000**
Common biotic stresses	Weeds	2.44	1.35	2.83	1.46	2.19	0.89	2.48	12.76	0.002**
	Bunts (Smuts)	1.88	1.09	2.03	1.37	2.71	0.98	2.20	51.61	0.000**
	Sunn pest	2.78	1.38	3.22	1.30	2.68	1.21	2.89	11.46	0.003**
Climate stresses	Heat	2.96	1.24	3.16	1.19	1.96	0.80	2.69	88.20	0.000**
	Hail	2.37	1.37	2.38	1.40	1.56	0.62	2.10	30.67	0.000**
Terminal drought	Dry end of season	2.77	1.23	2.90	1.40	3.20	0.87	2.95	9.75	0.008**
	Drought	3.67	1.32	3.95	1.27	3.59	0.97	3.73	12.47	0.002**
	Socio-economic variables	**Patterns of socio-economic vulnerability aspects of wheat farmers**						**Average***	**Chi-square**	**Sig**
Management Tips	Follow guidelines of agricultural institute	3.05	1.29	1.85	1.08	3.62	0.78	2.84	138.36	0.000**
	Change variety	3.28	1.26	1.83	0.98	3.41	0.80	2.84	130.68	0.000**
	Use of certified seed	3.01	1.27	1.82	1.03	3.22	0.92	2.68	95.09	0.000**
	Amount of seed	2.85	1.13	1.87	1	3.91	0.75	2.87	183.94	0.000**
	Winnowing and disinfected seeds used	3.13	1.21	1.65	0.99	3.24	1	2.67	134.13	0.000**
	Observe crop rotation	3.04	1.10	1.83	1.03	3.98	0.73	2.95	188.66	0.000**
	Cultivated area in relation to resource constraints (Water, mechanization and machines)	3.10	1.22	1.73	1.02	4.08	0.76	2.97	191.26	0.000**
	Early recognition of characteristics of the season	3.12	1.22	1.87	1.14	4.11	0.80	3.03	173.48	0.000**
	Management of planting date	2.44	1.17	1.53	0.86	3.69	0.89	2.55	199.18	0.000**
	Time of irrigation	2.46	1.09	1.57	0.89	3.75	0.87	2.59	202.52	0.000**
	Date of harvest	2.94	1.27	1.87	1.16	3.42	0.73	2.74	118.71	0.000**
	Proper adjustment of devices and pick-up speed control of drivers	3.24	1.30	2.07	1.17	4.31	1.10	3.20	158.41	0.000**
Supportive government policies	Effectiveness and efficiency of public sector's involvement in service delivery and seed production	3.91	1.22	3.44	1.44	4.63	0.49	4	57.45	0.000**
	Delivery of products, delivery and payment systems (across public sector)	3.45	1.35	2.81	1.49	4.27	0.54	3.51	71.45	0.000**
	Price stability of crops competing with wheat	3.54	1.26	2.70	1.52	4.26	0.81	3.50	80.02	0.000**
	Wheat import policy	3.74	1.20	3.37	1.54	4.96	0.19	4.02	146.67	0.000**
	Declaring good and acceptable guaranteed prices to farmers based on the international prices	3.67	1.21	2.78	1.51	4.76	0.52	3.73	148.86	0.000**
	Land consolidation policies	4.03	1.11	3.52	1.49	4.57	0.56	4.04	40.50	0.000**
	Determining the price of wheat before cultivation	3.48	1.22	2.72	1.56	4.68	0.57	3.62	134.69	0.000**

*Scoring pattern: very low damage = 1, low damage = 2, medium damage = 3, high damage = 4 and very high damage = 5.

Table A2. Descriptive statistics of wheat farmers' characteristics (mean, ANOVA test) according to vulnerability classes obtained from cluster analysis.

	Vulnerability patterns							
	Cluster 1 ($n = 90$)		Cluster 2 ($n = 118$)		Cluster 3 ($n = 183$)			
Characteristic	Mean	Std. Deviation	Mean	Std. Deviation	Mean	Std. Deviation	F	Sig
Total cultivated area (hectare)	15	45	18	28	5	4	10	0.000**
Cultivated area irrigated wheat(hectare)	9	24	7	8	3	2	9	0.000**
Yield (Tonne/ hectare)	4	2	5	2	2	1	80	0.000**
Income from agricultural products (€)	3395	4307	13460	40153	2518	1921	9	0.000**
Own consumption (%)	26	35	15	28	21	26	3	0.03*
Market sales (%)	74	35	85	28	79	26	3	0.03*
Work experience (year)	24	15	26	15	25	11	1	0.35
Income from wheat (€)	4613	26589	6502	17713	2121	2973	3	0.07
Income from non-agricultural products (€)	480	2702	2018	18539	1167	2309	1	0.5

**Significant difference at $p < 0.01$, *Significant difference at $p < 0.05$.