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REVIEW

Toward sustainable adaptation to future climate change: insights from vulnerability and resilience approaches analyzing agrarian system of Iran

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Abstract There is no certainty that adaptation to climate change is sustainable, and new approaches to assess current climate change adaptation trajectories are sorely needed. In this paper, we review the farmer-focused approaches (typical of vulnerability approaches) and agro-ecosystem-focused approaches (typical of resilience approaches). We propose that a combination of the two may be a better way to conceptualize sustainable adaptation to future climate change within an agro-ecological system. To test our hypothesis, we use the case study of Iran, a land that has shown both tremendous resilience and vulnerability in its agro-ecological system. We explore the changes that have occurred in the Iranian farming system and their implications for farmers' resilience to climate change through an integrated lens combining vulnerability approaches and resilience approaches. During the previous five decades, we describe how Iranian peasants have become small farmers, the land tenure system has changed from a traditional landlord-sharecropping system to family farms, and the quantity and quality of the agro-ecological resources have changed considerably. Our integrative approach provides important insights for both research and policy. We show that combining the two approaches can have far-reaching implications for farmers' adaptation to future climate change knowledge, policy, and practice since one approach aims to decrease farmers vulnerability and the other approach aims to build resilient agro-ecosystems.

Keywords Adaptation · Climate change · Development · Iran · Livelihood · Social–ecological systems · Sustainability · Systems thinking · Transformation · Water resources management

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1 Introduction

Agriculture and farmers are highly climate-sensitive, given their strong dependence on climate-sensitive natural resources (Howden et al. 2007; Meinke et al. 2009; Marshall et al. 2014). Although specific impacts are uncertain, climate change is likely to significantly exacerbate future food system performance through ecological degradation, fewer livelihood assets, and weak institutions, which in turn impact the poor (Ericksen 2008a; Reed et al. 2013). Within developing countries, impacts on food systems are likely to be particularly pronounced.

Much effort is therefore currently focused on building agricultural adaptation capacities around the globe (Pielke et al. 2007; Hashemi et al. 2012; Dow et al. 2013). Nevertheless, these efforts have had limited success in designing and implementing successful adaptation responses at various scales from local to global (Adger et al. 2005; Smit and Wandel 2006; Wise et al. 2014), and currently, there is no certainty that adaptation to climate change is sustainable, not only socially and environmentally but also regarding its implications for poverty reduction and human well-being (Eriksen and Brown 2011).

Given the potential scale and severity of projected climate changes, for both developing and developed countries, scholars call for anticipatory transformational adaptation rather than incremental adaptation to sustain agro-ecosystem systems in the long term (e.g., Pelling 2010; Kates et al. 2012; Dow et al. 2013; Rickards 2013; Mapfumo et al. 2015). Many forms of farming are not sustainable but resilient (Marshall et al. 2012), and a system transformation, particularly within these resilient systems, is necessary (Anwar et al. 2012).[1] For instance, in a study of Colombian smallholder farmers already facing the impacts of climatic changes, the author suggests a *transformative* rather than a *technical fix* adaptation (Feola 2013). Historically, agriculture in Australia has an excellent record of adapting to climate change and variability. However, it is unlikely that undertaking incremental adaptation measures will be sufficient to sustain these systems in the long term (Anwar et al. 2012). As such, farmers' *sustainable* adaptation to future climate change presents a critically important and challenging agenda for scientific, policy, and much more critically for farmers' communities.

Resilience and vulnerability have become concepts of interest in cases where complex socioecological problems prevail and are increasingly important for the study of the human dimensions of global environmental change (Janssen and Ostrom 2006). Resilience and vulnerability can have differing meanings, which may lead to confusion among both academics and practitioner communities[2] (Janssen et al. 2006; Nelson 2011; Hinkel 2011).

This paper does not attempt to resolve these discrepancies or take a stance on the value of discrepancies. Nor do we aim to conduct a comprehensive review of the emergence and development of these concepts in the context of global environmental change, and in particular climate change. Instead, we explore contributions of the areas of vulnerability and resilience research to the human dimensions (i.e., farmers) of adaptation to (future) climate change (Fig. 1; Table 1). Specifically, we address the issue of the unit of analysis and focus on *actor* and *system-focus* approaches. We use an example from Iran to argue

[1] Based on the scope and scale, adaptation to climate change measures can be classified into three types: coping measures, more substantial adjustments, and system transformation. These measures are ranged in nature from short-term copings and adjustments to long-term transformations (for details, see Moser and Ekstrom 2010). "Incremental adaptations" are classified as "coping measures" or "more substantial adjustments"; meanwhile, "long-term transformations" are with "system transformation" nature.

[2] For instance, some authors regard term resilience as a component of vulnerability framework (e.g., Adger et al. 2005); by contrast, others (e.g., Folke 2002) may consider resilience and vulnerability as antonym concepts (Turner 2010).

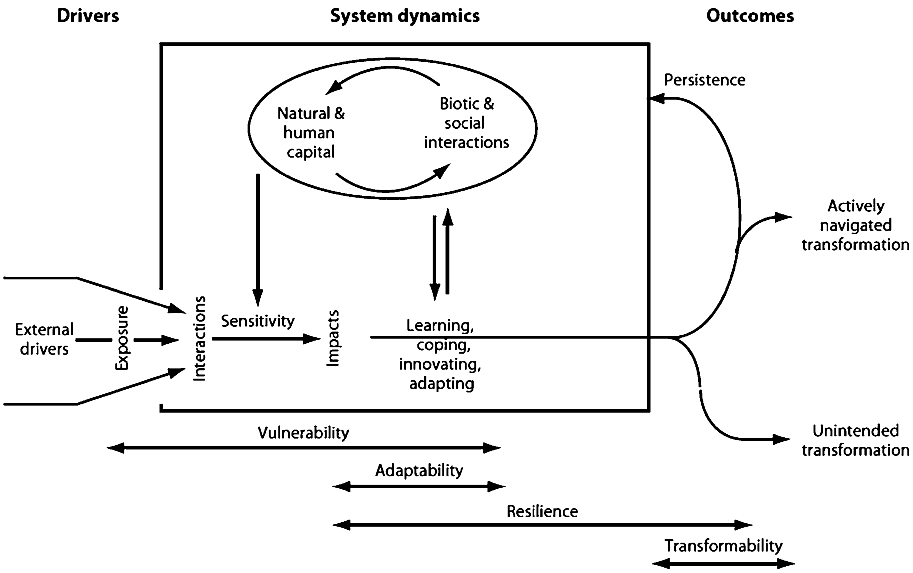

Fig. 1 Relationship between vulnerability and resilience as applied to adaptation as used in this paper (Vulnerability spans from drivers to system. Resilience spans from system to adaptation options. Adaptation draws on both resilience and vulnerability. See text for more details). Source: Chapin et al. (2009), with permission from Springer

that the important implications of climate change adaptation be incorporated into at least local knowledge and practice.

Vulnerability research tends to take an actor-focused perspective[3] in dealing with human and policy dimensions of adaptation to climate change. By contrast, resilience research usually takes an integrated and system-focused perspective (Nelson et al. 2007; Fischer et al. 2009; Miller et al. 2010; Turner 2010; Hinkel 2011).

While both approaches (actor-focused and system-focused) have contributed much to our understanding of farmers' adaptation to future climate change, they have significant limitations when considered separately, limiting the capacity to examine both farmers and agro-ecosystems. For example, farmers are embedded within households, whom exist within agrarian lands (properties or areas), and within communities. These rural communities exist within a broader landscape and local region and culture, each of which aggregate to the national and global scales (Marshall 2010). Although the emphasis in resilience is on considering the agro-ecosystem as a linked social–ecological system,[4] in practice the resilience community tends to consider the social domain only secondarily, and only after consideration of the ecological domain (Brown 2014).

[3] Through adopting an actor-focused perspective, vulnerability research concentrates on the actors' attitudes, values, interests, knowledge, and agency (Miller et al. 2010).

[4] Starting from 2000, the term social–ecological system has been dominating the literature in relation to resilience (and vulnerability; Berkes and Ross 2013). A social–ecological system can loosely be thought of as a combination of one or more social systems, as interacting social institutions that perpetuate society (humans), and an ecological system (biophysical and non-human biological units) in which social systems and ecological systems are considered as interdependent, coevolving, and coupled (Anderies et al. 2004; Folke 2006; Lyon and Parkins 2013; Lyon 2014) and in practice, they create a system that is more than the sum of its components of social systems and ecological systems (Berkes and Ross 2013).

Table 1 Contribution of vulnerability and resilience approaches to conceptualizing farmers' sustainable adaptation to (future) climate change (see text for more details)

Component	Vulnerability approach	Resilience approach	Contribution to farmers' sustainable adaptation	
			Vulnerability approach	Resilience approach
Adaptation of what/who	Social–ecological systems with primary focus on (sub)social systems, individuals, and community (farmers and communities)	Social–ecological systems with primary focus on (sub)ecological system	High	Low
Adaptation to what	Multiple and interacting stressors including climate change	Multiple and interacting stressors including climate change	Low	High
The purpose of adaptation	To reduce (social) vulnerability	To manage system resilience mostly by sustaining ecosystem services	High	Low
How to adapt	Maintain the system status quo or recover the system (reduce exposure and sensitivity; increase adaptive capacity)	Persistence, adaptability, and transformability (maintaining resilience of desirable states; eroding resilience of undesirable states)	Low	High

As an example, according to this perspective, therefore the dryland challenges are "How do we maintain these agro-ecosystems on development trajectories that provide us with the ecosystem services that we need (including food), or alternatively, if the current pathway is considered undesirable (e.g. if too little food and other ES [ecosystem services] is being produced), how can we destabilize existing feedbacks so as to open up for transformation, and then navigate toward a more desirable trajectory? This constitutes an essentially new way of thinking about the agro-ecosystems in semi-arid and dry sub-humid SSA [sub-Saharan Africa]" (Enfors 2013, p. 52).

This way of thinking, as Enfors (2013) states, provides promising insights into resilience and sustainability of agro-ecosystems, but at the same time fails to place *maintaining* farmers (social dimension) as the central objective. The focus, rather, is on *maintaining* an agro-ecosystem with the objective of providing ecosystem services. This may lead one to consider agricultural activities as the only option farmers have to earn their livelihoods in the present and future. Non-farming options have received little attention in resilience research. Thus, transformability—the capacity to create a fundamentally new system—of a social–ecological system, in this case an agro-ecosystem, is considered when ecological, economic, or social conditions make the existing system untenable (Walker et al. 2004).

In contrast, we contend that to build agro-ecosystems resilience to future climate change (see Table 2), we need to consider transformability and adaptability as well as persistence, even if the current system is tenable. Tenable does not necessarily mean best, or desirable. The vulnerability framework could help augment the resilience framework through its focus on reducing farmers' vulnerabilities. This may suggest shifts to new systems or livelihoods even if farming remains a tenable option.

Table 2 Applying resilience thinking concepts to determine how to adapt to climate change based on types of social–ecological systems (e.g., agro-ecosystems; see text for details)

	Desirable	Undesirable
Resilient	Persistence (I)	Transformability (IV)
Non-resilient	Adaptability (II)	Transformability (III)

In this paper, we call for a shift in the conceptualization and operationalization of farmers' sustainable adaptation to future climate change from *resilient agro-ecosystems* to *resilient farmers.* In doing so, we advocate for a shift toward increasing the ability of farmers to make a living through a diversity of options, thus increasing their capacity to adaptively respond to unpredictable change (Darnhofer et al. 2010a). This shift would unite the vulnerability framework's emphasis on farmers' livelihoods with resilience toward an integrated framework for adaptation, given that social, economic, and environmental perspectives would be considered.

Here, we consider four components for conceptualizing farmers' adaptation to (future) climate change: (1) adaptation of what/who; (2) adaptation to what; (3) the purpose of adaptation; and (4) how to adapt (adaptation strategies). Vulnerability and resilience frameworks approach each of these components in very different ways (see Table 1 for a brief summary). We review this in more detail below (Sects. 2 and 3) and then move toward an integrative approach that we argue is necessary for sustainable adaptation (Sect. 4).

2 Vulnerability approach to conceptualize farmers' adaptation to climate change

2.1 Adaptation of what/who

A vulnerability analysis places farmers at the center of the analysis. Farmers are regarded as the actors most negatively affected by climate change in a social–ecological system (Turner 2010). As the key actors within agro-ecosystems (Feola and Binder 2010), the vulnerability approach gives farmers highest priority when analyzing the vulnerability of these systems to climate change.

The farmer-focused view is dominant in adaptation studies that attempt to measure, rank, prioritize, and ultimately reduce an actor's vulnerability (Nelson et al. 2007). In particular, vulnerability research focuses on the attitudes, knowledge, behavior, access, entitlements, gender, ethical considerations, power, social change, conflict, equity, and agency of farmers (Miller et al. 2010; Larsen et al. 2011; Cote and Nightingale 2012). This approach allows the researcher to explore such subjects of importance as decision making and policy processes in regard to climate change adaptation (Miller et al. 2010; Agrawal et al. 2012).

In conceptualizing *adaptation of what/who* from a vulnerability perspective, the nature of the system (agro-ecosystems) and the issue of scale (spatial and temporal) are also important (Darnhofer et al. 2010a). For example, farmer households may be included, as may be their communities or their industries as a whole.

2.2 Adaptation to what

Vulnerability research tends to focus on drivers of change (socioeconomic and climate-related stresses) that are assumed to have actual or projected *negative* impacts (Hinkel 2011). Accordingly, such terms as hazard, stressor, threat, perturbations, and the like are frequently used in the literature, all with explicit meaning of danger for the system under investigation (IPCC 2001; Füssel 2007). Within the context of the IPCC framework for vulnerability (IPCC fourth assessment report 2007), "adaptation to what" constitutes a similar concept to the exposure function, where vulnerability is recognized to be a function of exposure, sensitivity to change and adaptive capacity (see Marshall et al. 2013).

2.3 The purpose of adaptation

From a vulnerability perspective, adaptation processes should seek measures to reduce vulnerability (or increase resilience). Hence, *successful* adaptation needs to be judged on its role in reducing short- and/or long-term vulnerability of farmers in a changing climate. It should enhance individuals' and communities' well-being, increase access to resources or insurance, and enable specific populations, especially the disadvantaged, to recover from loss (Adger et al. 2005; Patt et al., 2008; Chapin et al. 2009). Doria et al. (2009) suggest that "successful adaptation is any adjustment that reduces the risks associated with climate change, or vulnerability to climate change impacts, to a predetermined level, without compromising economic, social, and environmental sustainability" (p. 817).

Similarly, from a vulnerability perspective, *maladaptation* describes situations in which the objective(s) of adaptation has not been met, or situations where adaptation measures have worsened outcomes. Barnett and O'Neill (2010, p. 211) define maladaptation as "action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups."

2.4 How to adapt

Vulnerability research strives to maintain the system status quo, its recoverability (bounce back) or its ability to cope with the facing stressor(s). Little literature exists that dictates how to adapt other than suggestions that creativity and innovation are important (Folke et al. 2005; Dowd et al. 2014). Adger et al. (2005) propose four normative criteria to be considered for the evaluation of successful adaptation to climate change, which can help guide farmers and agricultural industries to decide how to adapt: effectiveness, economic efficiency, equity, and legitimacy.[5] They emphasize that these criteria are context-specific and change in importance, weight, and value from one individual, community, or society to another and similarly from time to time (Adger et al. 2005). In some regions, specific technological advancements are available to assist famers have access to new ideas and tools (e.g., Howden et al. 2007).

[5] Adger et al. (2005) define these criteria in this way: Effectiveness means the capacity of an adaptation action to achieve its stated objectives. Efficiency relates to costs and benefits of adaptation to climate change. Equitable adaptations need to be evaluated considering outcome (i.e., who wins and loses from the adaptation) as well as who decides on the adaptation to take. Finally, legitimacy relates to decision about climate change adaptation and regards to some extent the decisions made are acceptable to those who made the decisions and those had no role in decision making but are assumed to be affected by the decisions.

3 Resilience approach to conceptualize farmers' adaptation to climate change

Resilience theory was first introduced as a systems science; however, it almost exclusively concerned the behavior of ecological systems (Holling 1973). It has since evolved to describe coupled social–ecological systems (Folke 2006), including agricultural systems (Darnhofer et al. 2010b). Resilience theory is widely used in sustainability research (Fischer et al. 2009).

Here, we distinguish among the concepts of resilience as a non-normative property of social–ecological systems (i.e., it can be a positive or a negative property depending on context; Van Apeldoorn et al. 2011; Anderies et al. 2013), which is defined as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Kinzig et al. 2006) and resilience thinking, which sees transformability as another option for sustaining a social–ecological system (Folke et al. 2010; Lyon 2014) apart from resilience. In this paper, by referring to a resilience approach we mean resilience thinking.

3.1 Adaptation of what/who

In conceptualizing farmers' adaptation to (future) climate change, the resilience framework sees agro-ecosystem as an interlinked and interdependent social–ecological system, coevolving and interacting at various levels and scales (Ericksen 2008a; Feola and Binder 2010).

Since resilience is a system-level property of a social–ecological system, emphasizing dynamics of a social–ecological system, dynamics within both the human subsystem and the environment subsystem and between the two linked subsystems are key to understanding the nature of the agro-ecosystem in question. In other words, when one determines who or what is adapting, the main focus of the resilience approach is on the relationships and interdependencies among subcomponents of the agro-ecosystem (key variables). As Armitage et al. (2012) have pointed out, resilience in a coupled social–ecological system has however been better theorized within the ecological subsystem, and has been regarded as more influential than the social subsystem.

3.2 Adaptation to what

Resilience research acknowledges the multiple stressors or drivers of change affecting farmers when adapting to climate change. Change is interpreted not as a disturbance,[6] but as a trigger for the reorganization of resources and for the renewal of the farm organization and activities. According to the resilience approach, given uncertain farm and societal dynamics, farmers need to account for unexpected developments (Darnhofer et al. 2010a, b). One needs to be prepared for "surprises" and learn to live with them (Kinzig et al. 2003; Folke 2006). Hence, since climate predictions are inherently uncertain, the resilience-based approach is particularly apt for managing the impacts of climate change (Marshall 2010). In practice, however, resilience research tends to focus not on adapting to

[6] In social–ecological systems' context, disturbance is defined as any relatively discrete event in time that disrupts social or ecological communities and changes the social or physical environment (Fleischman et al. 2010).

"surprise" but rather on specific change events such as drought or flood, or pests, or diseases (Anderies et al. 2006).

3.3 The purpose of adaptation

Broadly speaking, managing a social–ecological system's resilience can be regarded as both the definition and purpose of adaptation (Walker et al. 2004). Setting an objective for adaptation (and for sustainability) within an agro-ecosystem is relatively new for research in this area (Darnhofer et al. 2010a). Increasing an agro-ecosystem's productivity and efficiency has received most of the attention within research and development programs. A resilient agro-ecosystem is generally recognized as one that has the ability to generate food and other vital ecosystem services over time for a particular population; maintaining that capacity over time necessitates having the capacity to cope with the drivers of change (Gordon and Enfors 2008).

3.4 How to adapt

Resilience research emphasizes that "adaptation to environmental change is best formulated as an issue of system resilience" (Nelson et al. 2007, p. 396). The resilience approach focuses on how to adapt to and shape change (Chapin et al. 2009) and stresses a change in a perspective aiming at controlling changes in a social–ecological system to a perspective wishing to cope with, adapt to, and shape changes (Folke 2002). As shown in Table 2, given two criteria simultaneously (resiliency and desirability), one may judge which aspect of resilience thinking (i.e., persistence, adaptability, or transformability) needs to be considered when considering how to adapt to social–ecological change (e.g., climate change). If one is in a desirable state, the challenge is to enhance or maintain resilience. If one is in an undesirable state, the challenge is to erode resilience (if resilience is high) and create the conditions for a positive transformation.

4 Toward an integrated approach to conceptualizing farmers' sustainable adaptation to future climate change

To develop insights into adaptation to climate change within an agro-ecological context, we contend that both vulnerability and resilience approaches provide necessary approaches and that relying on either one approach may lead to unsustainable adaptations, or even maladaptations, particularly in the longer term (see Table 1).

Vulnerability research suggests that the vulnerability of farming systems is not reduced unless special attention is focused on farmers, especially the most vulnerable ones (Chapin et al. 2009; Turner 2010). Indeed, some authors propose that food systems' resilience need to be reframed from a system-oriented to a more people-centered perspective (e.g., Bohle et al. 2009). However, as Hauck (2010) argues, such overemphasis on agency in conceptualizing and operationalizing resilience [and adaptation] can lead to downplaying or overlooking important structural features. To understand how actors interact today, it is necessary to take into account historical legacies of power and value conflicts (Hauck 2010). Ericksen (2008b) also supports applying a systems' approach to food systems and giving attention to macrolevel or structural features, arguing that in complex systems such as agricultural systems, there is an interplay between structure (which is usually at a broader or macrolevel) and agency (which is at local or microlevel). The institutions and structures that govern people's actions however are also modified over time as a result of individual actions.

To build resilience and sustainability in agriculture to future climate change, cross-scale interactions should also be considered. A systems' approach may help through taking into account the feedbacks and cross-scale interactions within food systems that may also increase vulnerabilities in the future. Shifting from a focus on the dynamics of farmers' adaptation in a changing climate at the household-level to considering a broader spatial and temporal scale that links adaptation outcomes to processes might also be facilitated (Ericksen 2008a). Instead of seeking to eliminate vulnerability in a system of interest, an integrated approach would assume that the vulnerabilities are an inherent part of the system. According to this perspective, therefore the research needs to identify and define acceptable levels of vulnerability and to maintain and increase the capacity to respond to vulnerability (Nelson et al. 2007).

Similarly, a resilience approach can bring critical perspectives to sustainable adaptation to future climate change as it is argued that the key to sustainability lies in the resilience of whole systems and not in optimizing isolated components to be more productive or in keeping the status quo of the system (Kim and Oki 2011). We believe that conceptualizing (and also operationalizing) sustainable adaptation means to shift from seeking optimal adaptation to a robust (resilient) adaptation (Wilby and Dessai 2010). The key learning is that an integrated approach using both a resilience and a vulnerability approach enables sustainable adaptation to future climate change to be evaluated.

5 Iranian farmers' adaptation to (future) climate change and variability (1962–present)

This section uses the example of Iran to illustrate our proposed approach for conceptualizing farmers' sustainable adaptation to future climate change and variability. In Iran, agriculture is considered among the most climate-sensitive sectors in the country (Koocheki et al. 2006; Koocheki and Nassiri 2008; Shahbazi and De la Rosa 2010; Gohari et al. 2013; Moradi et al. 2013; Roshan et al. 2014). Iran's climate is generally (70 %) arid or semiarid. The average precipitation is about 250 mm per year, less than one-third of global average, with less than 100 mm of annual precipitation in most of the country (Gorjian and Ghobadian 2015). Since most precipitation occurs during winter months, during the rest of the year, irrigation is necessary for agricultural production in most of the country, with the exception of the Caspian provinces of Mazandran and Gilan (Seyf 2006). In recent decades, frequent droughts and floods have negatively impacted water resources and water management in Iran (Gorjian and Ghobadian 2015). According to the majority of projections, climate change is expected to exert pressure on Iran's water resources by making the region hotter and drier. In addition, it is predicted that climate change has major implications for agricultural production and food security in Iran (Faramarzi et al. 2009; Madani 2014). According to the International Water Management Institute (IWMI), by 2025 Iran will face a water crisis (Gorjian and Ghobadian 2015).

In calling for an integrated framework to conceptualize farmers' sustainable adaptation to (future) climate change, we conceptualize resilience as a system-level characteristic (in contrast to actor level) pertaining to farmers themselves and not their agro-ecosystems (i.e., a shift from *resilient agro-ecosystems* to *resilient farmers*). Accordingly, resilience is

Table 3 Comparison of some characteristics of historical periods of Iranian farmers' livelihood systems (see text for more details)

Characteristics	Prior to 1962	1962–1979	1979–2000, 2000–present	?[b]
Institution[a]	Landlord-sharecropping system	Family farm, commercial holdings	Family farm	?
Resource users	Landlord-peasants	Peasants	Farmers	Non-farmers
Resource	Untapped	Unsustainable use	Unsustainable use	Degraded

[a] Land tenure system

[b] a period in the future

defined as the persistence of the fundamental structure, function, and identity of an agriculture-based livelihood system in the face of (future) climate variability and change. To assess the resilience of the livelihood system, here we consider interactions between three components of institutions (e.g., land tenure system), resource users (e.g., farmers, technology used for water exploitation), and the resource (e.g., water[7]) they depend on and govern (Anderies et al. 2004; Ostrom 2007). This section therefore explores and analyzes Iranian farmers' resilience through analysis of resilience of on-farm-based livelihood system (a livelihood strategy that is agriculture-based) to climate change and variability in Iran during the previous five decades.

By reviewing the relevant literature, as the main methodological tool of this study, from the peer-reviewed publications and in particular previous research dealing with the history of socioeconomic transformation of an Iranian village community of Shishdangi (1967–2002; Ajami 2005), the changes in the water resource management system in Iran (Ardakanian 2005), the history of agricultural development in Iran (Rezaei-Moghaddam et al. 2005), the history of Iran's agricultural sustainability with regard to water use (Forouzani and Karami 2011), and the history of water management in Iran (Yazdanpanah et al. 2013a), as well as considering interactions between institutions, resource users, and the resource as factors determining the *resilient farmer*, the main analytical framework of this study, we examine distinct four periods in the history of Iranian farmers' livelihood system during five decades ago: prior to 1962, 1962–1979, 1979–2000, and 2000–present (Table 3; note the rightmost column of Table 3 describes a period in the future which is covered in the Sect. 5.6). It should be noted that these distinct periods are based on our opinions and interpretations of history. Therefore, alternative interpretations may be possible.

5.1 The period prior to 1962

Before the implementation of land reform in 1962, Iran's agricultural sector involved almost no use of modern agricultural inputs such as machinery, chemical fertilizers, and limited irrigation. In the nineteenth century, irrigation methods included qanats, groundwater wells, rivers, natural or induced floods, and manual irrigation. The most common

[7] In this section, we focus mainly on water resources. Iran is currently experiencing a serious water crisis. Both surface and groundwater resources in Iran are in a critical situation. By 2021, it is predicted that Iran's total per capita annual renewable water (which currently stands at less than 1700 m^3) will reach to about 800 m^3 (1000 m^3 is the global threshold.) (Madani 2014; Gorjian and Ghobadian 2015; For more information on water resources in Iran, see Madani (2014)).

form of irrigation by far, however, was the qanat.[8] In the early 1960s, the total number of qanats in Iran was between 30,000 and 50,000, distributing an estimated 75 % of irrigation water. This period was associated with little threat to the ecological subsystem. Although the agriculture sector's productivity was low during this period, it was able to meet national food demand because of the relatively small population and low per capita consumption (Rezaei-Moghaddam et al. 2005; Marjanizadeh et al. 2009). Ajami (2005) reports from Shishdangi: Before the land reform occurred, Shishdangi's social structure was nearly homogenous.

The dominant agricultural production system of this period could be called the traditional landlord-sharecropping system[9] in which the land was divided into a number of fields, each of which was worked cooperatively by a team (Buneh). The Buneh was a farming institution typically including some four to six sharecroppers[10] with approximately the same economic and social status. The main function was to exploit productive land and the available water in an efficient way. In addition, being a member of Buneh had an advantage of strengthening socioeconomic positions for peasants in the countryside. For example, Buneh played a pivotal role in water governance (Yazdanpanah et al. 2013a). Such collective farming and sharecropping, which was formed by a complex set of interrelated social and ecological factors (Salmanzadeh and Jones 1981; Koocheki and Ghorbani 2005), constituted the dominant agrarian institution that mediated the relationship between resource users (peasants in this case) and the resources. Ajami (2005, p. 331) describes this period's agrarian structure by three characteristics: "the predominance of an (absentee) landlord-sharecropping system; low capital investment in agriculture, leading to low productivity and poverty of the peasants; and a pattern of landlords' domination over the social and economic institutions of the countryside." Salmanzadeh and Jones (1981) also describe this agrarian structure by "landlordism, peasant sharecropping, and relatively low level of agricultural production and productivity" (p. 199).

We hypothesize that the persistence of this regime to climate variability and change (when peasants whose livelihood depended entirely/largely on subsistence agriculture) was established (sources of resilience) through an existence of relatively low population, low standards of living, homogenous social structure, and resilient institutions (i.e., landlord-sharecropping system and Buneh) to climate variability and change. Meanwhile, this regime in which sharecroppers depended entirely on the landowners for their livelihood was vulnerable to the land reform of 1962 because of the dissolving of its critical institution, the landlord-peasant system. This period ended with the implementation of land reform in 1962 (see below).

5.2 The period 1962–1979

To modernize the agriculture sector and the countryside, Iran's government took several initiatives. The radical land reform program can be described as the most contributing

[8] Qanat technology consists of a tunnel with many vertical wells. Through these structures, water flows to the lowest levels, and groundwater is then brought to the surface, relying upon gravity alone. Qanat technology was developed in Iran's arid regions centuries ago to make use of groundwater resources for areas where it is most needed, especially for agriculture and habitation. Some qanats are still in use in the country (Jomehpour 2009; Forouzani and Karami 2011).

[9] *Nizam-i arbab-rayati.*

[10] Sharecropping in traditional agriculture of Iran was based on an effective system of socioeconomic incentives. In this arrangement, the land was often in common, and other production factors such as labor, animals, fields, or farm products were shared or exchanged among community members (Koocheki 1996).

factor and was launched in 1962 and implemented in three phases across a decade. Iran's agricultural and rural communities were transformed in the early 1960s. This was a period in many developing countries where governments took the initiative to "modernize" their agricultural sectors and to shift from traditional small-scale agricultural entities to larger-scale forms of agriculture (Reardon et al. 2009). Within a short temporal scale, the landlord-peasant land tenure system converted to mostly family farms and commercial holdings. The critical mediating role between resource users and the resources (Barnes 2009) lost its fundamental identity (resilience).

The collapse of the main institutional arrangements in the countryside we believe led to a loss in the overall resilience of Iranian farmers' on-farm-based livelihood regime to climate change and variability. As a result of the land reform, some 52–62 % of the total land or some 6–7 million hectares of agricultural land were redistributed to the occupant sharecroppers and tenant farmers, leading to a substantial increase in peasant proprietorship (Ajami 2005). Post-reform years were associated with profound changes in resource users (transforming from landlord-peasant to peasants), institutions (disintegration of sharecropping, and Buneh and establishment of commercial holdings), and the beginning of overusing the resources.[11] Through farmers' adoption of modern technologies such as electric and diesel-pumped wells, they were able to overpump (Balali et al. 2009; Forouzani and Karami 2011). Between 1960 and 1974, positive production growth rates[12] of 3–4 % annually were reported (Karshenas 1990 as cited in Ajami 2005). Modern technical inputs such as chemical fertilizers, pesticides, and agricultural machinery, and implements were widely promoted in this period (Deihimfard et al. 2007 as cited in Yazdanpanah et al. 2013a). For example, in the early 1960s, the use of chemical fertilizers was about 32 thousand tons per annum. This figure reached 675 thousand tons by the mid-1970s (21.1 % increase in average annual growth rates). Furthermore, during these years, investment in agricultural machinery grew from 2.3 to 16.4 in real terms (Karshenas 1990) (Table 4).

In the period after the land reform program was launched, which was combined with other state's initiatives including the establishment of the national agricultural extension organization, large-scale public and private agricultural production systems were also launched (e.g., agribusinesses, farm corporations, and the agricultural production cooperatives). They received subsidized inputs and improved communication. Iranian agriculture was supported by a surge in the inflow of financial and real resources. In addition, over this period the agricultural terms of trade[13] were improved considerably (Karshenas 1990).

5.3 The period 1979–2000

5.3.1 1979–1988

In the late 1970s and toward the 1980s, two *shocks* happened which had profound change for Iran's economy and society: In 1979 the Iranian revolution and in 1980 the war between Iran and Iraq occurred, in which enormous human and material losses were suffered. In 1986, a decline in oil prices also strongly impacted on Iran's economy, which was in recession (Ghassemi et al. 2002).

[11] For example, between 1960 and 1974, approximately 5 million hectares of new land was brought into cultivation (Karshenas 1990 as cited in Ajami 2005).

[12] Between 1959 and 1977, production growth rates for wheat, barley, rice, cotton, sugar beet, tea, and oil seeds were 4.3, 3.0, 4.9, 2.6, 12.2, 6.0, 12.9, respectively (Karshenas 1990; see Table 4).

[13] Prices of agricultural commodities compared with the price of farm inputs.

Table 4 Iranian agriculture's technical inputs utilization and agricultural production (1959–1977; source: Karshenas 1990)

	Annual average			Average annual growth rates[a]
	1959–1961	1968–1970	1975–1977	1959–1977
Use of chemical fertilizers (1000 Tons)	31.7	212.3	675.3	21.1
Real investment in machinery and implements[b]	2.3	3.6	16.4	13.0
Volume of output (major products, 000 tons)				
Wheat	2876	4253	5667	4.3
Barley	854	1128	1377	3.0
Rice	698	1020	1500	4.9
Cotton	332	522	305	2.6
Sugar beet	741	3240	4673	12.2
Tea	37	79	95	6.0
Oil seeds	16	53	112	12.9
Real value added[b]				
Farming	58.5	90.2	111.7	4.1
Animal husbandry	27.0	32.0	45.5	3.3
Total agriculture	86.8	124.1	161.3	3.9

[a] Cumulative growth rate between 1959–1961 and 1975–1977 mid periods

[b] In bn Rials, 1959 prices

After the revolution, the government described the goals for agriculture considered before the revolution as "misconceived" and "anti-rural"; instead, it envisioned agriculture as the "axis of the country development" and also declared increased production, enhanced productivity, farmer welfare, and self-sufficiency in food production as the main reasons for implementing agricultural and rural development programs (Mojtahed and Esfahani 1989; Yazdanpanah 1994; Ghadiri Masoum and Najafi kani 2003; Karamidehkordi 2010). Some land reforms were launched that were a complete reversal of the land policies that had been implemented before the revolution: The reforms disintegrated large-scale public and private agricultural production systems, and replaced them with individual and group peasantry holdings (Lahsaeizadeh 1990; Azkia 1994). Extension and development institutions like the Centre for Agricultural, Rural, and Tribal Services and Jihad-eh Sazandegi were established to contribute to rural development and poverty eradication through activities such as input use and redirecting government resources toward smaller investment projects (Shakouri 2005; Balali et al. 2011).

The government supported agriculture with direct investments in agriculture, and with remarkable increases in the supply of inputs.[14] It tried to keep the price of the inputs unchanged (Yazdanpanah 1994). After the Revolution (1980s compared with 1970s), the overall terms of trade turned in favor of agriculture (Mojtahed and Esfahani 1989). In general, early after the revolution (1979–1988), resource users (i.e., small farmers) were supported directly by the central government interventions.

[14] For instance, from 1978 to 1986, fertilizer use in the country grew from about 581,000 tons to 2,306,500 tons, distributed amounts of improved seeds for producing wheat and barley increased from 60,000 tons to 873,000 tons during 1978–1982 (Mojtahed and Esfahani 1989), and number of tractors in use increased from about 78,000 in 1979 to 135,000 in 1985 (Shakouri 2005).

5.3.2 Postwar years

During the years 1989–1992, oil prices rose. Between the years 1989 and 1999, the agricultural sector was considered to be the key sector for Iran's economic growth and development in Socioeconomic Development Plans (Saleh et al. 2008). From 1987 to 1991, the area under food grains production increased annually by about 2.5 %. Wheat[15] had the largest allocation among food grains with 73 % of the total area of cultivation (Yazdanpanah 1994).

Iran has witnessed a rapid population growth during the second half of the twentieth century. In 1961, the population was about 19.5 million (Forouzani and Karami 2011). It increased to more than 35 million in 1979. During the final two decades of the twentieth century, Iran's population almost doubled (Madani 2014). The highest annual growth rate of 3.9 % happened in 1986, during the Iran–Iraq war. However, this rate was decreased significantly to 1.45 during the years 1986–1996 (Alizadeh and Keshavarz 2005). While the urban population comprised 38 % of the total population in 1966, it increased to 61.3 % in 1996 (Karamidehkordi 2010).

A comprehensive national wheat program allocated high input subsidies to producers as well as to consumers on flour and bread prices. The subsidies relied on oil prices rising between 1989 and 1992. Within 17 years (1979–1996), wheat production doubled nationwide (Najafi 2001; Ghassemi et al. 2002). Growth in food production exceeded population growth, and self-sufficiency ratios were estimated in 1997 at about 80 % for wheat, 90 % for animal protein, and 100 % for poultry, milk, and cheese (Ghassemi et al. 2002).

5.4 2000–present period

In recent years, two major droughts have happened across the country. From 1999 to 2004, the first drought affected almost the whole country. In 1999–2000, a persistent drought harshly impacted 18 of the country's 28 provinces. The drought was considered the worst in 35-year record (the long-term Iran's average of 249 mm was decreased to just 138.3 mm nationwide). The losses of drought[16] estimated to be USD 1.7 billion (OCHA 2000). It impacted seriously agricultural imports and exports. The government imported heavily wheat, barley, and other agricultural products to fulfill nation's food needs (Salami et al. 2009). The second drought occurred in 2008 and affected some parts of the country (Shahbazbegian and Bagheri 2010).

In addition, serious environmental problems started to affect Iran such as desertification, soil erosion, rangeland and forest degradation, rainfall runoff and floods, high sedimentation in lakes and reservoirs, and sandstorms (Chizari and Ommani 2009). According to Emadodin et al. (2012), the total cost of soil and water degradation and use of fertilizers in agriculture are estimated about 157,000 billion Iranian Rials (US $12.8 billion). Approximately 77 % of the irrigated lands deal with some levels of salinity. From the 1970s to the mid-2000s, the groundwater exploitation in the country has been increased around fourfold. In 2008, the groundwater table fell by around 1.14 m on average.

[15] In Iran, wheat is a very important crop to food security. It accounts for 40 percent in supply of the dietary energy and 45 % in supply of the total protein (Ghassemi et al. 2002).

[16] For more information on economic impacts of the drought on the economy of Iran, see Salami et al. (2009).

From a decade ago, Iran has been dealing with a major water crisis. The situation worsened because of two severe droughts in 2008 and 2009. As a result, 3 million tons of wheat and barley were estimated to be lost. It is likely that continuing high population growth and climate change will deteriorate the situation even further. It is predicted that the severity and frequency of extreme events (such as droughts) will increase because of climate change. An estimated 50 % reduction in per capita water availability is predicted by 2050 for Iran (Balali et al. 2009) (Yazdanpanah et al. 2013a). Based on SRES[17] A1 storyline and scenario family, IPCC predicts an average temperature rise of 2 to 3.5–4 °C for Iran in the next 30–100 years. In addition, this prediction indicates a considerable reduction in the precipitation and 30 % reduction in cereal production by next 30 years for Iran (Hosseini et al. 2013).

In addition to the environmental shocks, Iranian farmers' livelihoods have recently been further affected by economic shock. Aiming to increase productivity in the agriculture sector recently, the Iranian government has decided to change its policy of supporting both agricultural producers and consumers through subsidies. The subsidy reform plan has been described by the government as the "biggest surgery" to the nation's economy within the previous five decades (PressTV 2010). Instead, the government will make a direct payment to all income groups (Karamidehkordi 2010; Azamzadeh Shouraki et al. 2013; Ansari et al. 2014). Azamzadeh Shouraki et al. (2013) found that a reduction in the energy subsidy would reduce energy consumption slightly and would reduce the value added of the agricultural sector in the long run. These authors argued that implementing a policy of reducing/cutting the energy subsidy may cause a sudden increase in the prices of agricultural inputs (price shock) and eventually also be harmful to the agricultural sector. They suggested that this policy need to be implemented in a gradual way.

In another study, Ansari et al. (2014) explored "the distributional consequences of subsidy removal from agricultural and food industry sectors in Iran." Their results revealed that the removal of all subsidies from agricultural and food industry sectors has distributional consequences for the Iranian households. According to the results, the most negatively affected Iranian households are the rural low-income households.

5.5 Discussion

In previous sections, we mostly tracked Iran's agriculture sector performance in terms of its total production across different periods. The resilience of Iranian farmers' to climate variability and climate change appears to have been derived from the interactions between institutions, resource users, and the resources they depend on and govern (Table 5). In the following, we explore these new considerations and what they mean for the future adaptation to climate change of Iranian agriculture.

The radical land reform of 1962 negatively affected all three components of *resource, resource users, and institutions*. These impacts were in sharp contrast to the positive impacts of the land reform on the growth and the terms of trade of the agriculture sector, as a result of using Green Revolution technologies, among others. There have been many controversies over the impacts of the land reform of 1962, but most researchers concluded that the reform could not have been successful in improving the living conditions of the majority of Iranian peasants in the countryside (especially the poor), and as a result, the inequality between rich and poor villagers might have widened (Amid 1990; Karshenas 1990; Ajami 2005). In fact, the reform was ineffective for the poorest 60 % of rural Iranian

[17] The IPCC Special Report on Emissions Scenarios.

Table 5 Dynamics of small farmers' resilience in Iran: a timeline of events (these levels are based on our opinions and interpretations of history)

Year(s)	Event	Impact on resource' resilience	Impact on institution' resilience	Impact on resource users
1962–	Land reform, market integration, extension services, subsidized inputs, improved communication	↓	↓	↓
1979	Revolution	↓	↓—	↑
1979–	Land reform	↓	↓	↓—
1980	War	—	—	↓
1988–	After war (rapid, high population growth, international sanctions, etc.)	↓	—	↓
1999–2003 and 2008	Drought	↓	—↑	↓
2010	Eliminating the most of agricultural subsidies	↑	—	↓

households as they either received no land (more than 30 % of the rural households, who were the landless laborers, received no land.) or received very small plots of below 2 ha. Such plots could not support their livelihoods even at the subsistence level (Amid 1990; Karshenas 1990; Balali et al. 2011).

In addition, the development of the agricultural sector after the land reform in Iran was based on the capitalist agriculture's path of development. This new configuration lead to the accumulation of new lands and income gains for large farmers and therefore increasing inequality between the large and small farmers. In other words, a considerable growth in the agricultural terms of trade gained during this period was distributed mainly among large-scale farmers (Amid 1990; Karshenas 1990). Ajami reports from Shishdangi the same phenomenon: Some 35 % of the households who were mostly wage laborers[18] prior to the implementation of the land reform did not hold cultivation rights[19]; they were not included among the beneficiaries of the program (Ajami 2005). He discusses other possible explanations for this increased inequality between poorer and richer peasants. For example, richer peasants adopted more Green Revolution technologies and employed better farm management skills.

Internal power structures, as examples of changes in institutions, originated and were kept mainly within the village, were replaced with external power structures of the central government. The land reform program implemented a top-down approach, in which the peasants' contribution to planning and implementation of the program was very low. It dissolved traditional institutions, formed and operated "internally" with active involvement of peasants (i.e., Buneh), which were effective based on the traditional agriculture norms for use of resources and conserving qanats, and replaced them with externally developed institutions (e.g., The Rural Cooperative Societies). These new institutions mostly suffered from bureaucracy, and they were preoccupied with providing peasants with credit rather than fulfilling the important functions accomplished by the disintegrated traditional institutions (Karshenas 1990; Karamidehkordi 2010).

[18] *Khwushnishins.*

[19] *Nasaq.*

With regard to resource users and institutions, Ajami reports: “The Shishdangi data show the development of a dualistic agrarian structure, the demise of sharecropping, the disintegration of the Bunah system, and deterioration in the socioeconomic conditions of the Khwushnishins, which reflects the broader socioeconomic trends occurring in rural Iran at this time” (Ajami 2005, p. 333).

In sum, development policies implemented during the early 1960s to late 1970s resulted in exacerbated peasants’ poverty, uneven development, and environmental degradation (Rezaei-Moghaddam and Karami 2008). This period represents the (over) exploitation of resources well beyond the ecological thresholds. As a result of new changes during this period, sources of resilience seemed to have shifted from within rural areas to external ones.

During the late 1970s to late 1980s, revolution, war, and land reform impacted on farmers’ livelihood system’s resilience to climate variability and change (Table 5).

Over this period, the revolutionary government supported peasants (especially the poorer households and agriculture sector) with a special focus. After the revolution, the objectives of agricultural development and rural development were different from pre-revolution objectives both in direction and also in means of achievement (Yazdanpanah 1994). The imposed limitations on imports of certain food items in the initial post-revolutionary years made food self-sufficiency a necessary objective for the country. Toward this direction, availability of low-interest funds for small farmers was increased and the government provided them with subsidized fertilizers, seeds, and agricultural implements (Behdad 1989). Consequently, the inequality divide between small and large peasants was narrowed (Behdad 1989; Saleh et al. 2008). On the other hand, the development institutions established by the government suffered from some malfunctionalities and could not become a suitable substitution to the disintegrated traditional institutions.

The land reform program implemented after the revolution could not resolve the issue of landlessness in the countryside where land scarcity was coupled with a rapid population growth. Actually, Ajami reports from Shishdangi, a substantial rise in the absolute number of households without agricultural land as a result of the land reform (Ajami 2005).

However, since the postwar years, the Iranian economy changed its direction. At the national level, the years 1989–1996 were a period of reversing the transitional changes in the first post-revolutionary decade, or the “de-involution” of the economic structure (Behdad and Nomani 2002). In the early years after the war, due to the elimination of some subsidies and implementation of structural adjustment and economic liberalization policies by the government and due to considerable inflation, the inequality of incomes among the rural society increased. In the following years, the percentage of the rural poor decreased, as a result of the government’s investments in rural infrastructure and control of the inflation rate. But, with repeated drought events, again the percentage of rural poor rose (Shakouri 2005; Saleh et al. 2008; Khaledi and Haghighatnezhad shirazy 2012). Considering the period of 1971–2006, Khaledi and Haghighatnezhad shirazy (2012) found that the average annual absolute poverty for rural areas was 36 %, and this figure culminated in 1972–1973 to 48 %.

Since 2010, the government has considered removing most agricultural subsidies. The subsidies have acted as a source of resilience for farmers against market shocks and climate change and variability’s impacts. Removing subsidies may decrease the agricultural terms of trade, particularly for small farmers.

5.6 Off-farm-based livelihood period

Severe droughts as of 2000 and during the last decade made it clear how Iranian agriculture is vulnerable to some social–ecological thresholds. We call this period as the "off-farm-based livelihood" (the rightmost column of Table 3). In the future, climate change may reduce farm-based livelihoods for many Iranian agricultural systems and rural communities.

According to a survey of 255 farmers conducted in 2011 in Fars Province, southwest Iran, Keshavarz and Karami (2014) reported that a large percentage of farmers made some adjustments in response to drought. However, their coping strategies were not effective enough to mitigate the negative impacts of drought; consequently, during the middle and end stages of the drought, many farmers experienced serious difficulties. Most of the surveyed farmers lacked the necessary resources or access to affordable loans. To keep farmers on the farm during long and severe droughts, the authors therefore recommended that the government should play a major role and provide farmers with social protection services apart from agricultural interventions.

In addition, a study conducted in a village in southern Iran, where farmers have been coping with high rainfall variability and drought for many years, found that farmers, especially the poor, were very vulnerable to drought as they had only limited resources from various forms of capitals (e.g., financial, social, human capital; Yazdanpanah et al. 2013b). According to the authors, this situation could lead to a state where farmers end up in the poverty trap.

In these situations, removing subsidies may provide a window of (long-term) opportunity by decreasing the farmers' resilience through a decrease in the agricultural terms of trade, motivating farmers to transform their on-farm-based livelihood system. At the macroscale (national level), the agricultural sector consumes the greatest amount of water (more than 90 %) each year. Given that Iran is currently dealing with drinking water shortages in many parts of the country, planners and the public are deeply motivated to think about decreasing the share of total water to agriculture. However, transformation would not be easy to implement in the current Iranian context. A key challenge for transformation in response to changing climatic conditions is to have sufficient capacity across temporal and spatial scales to implement new strategies (Marshall et al. 2014). However, about 80 % of all Iranian farmers are either illiterate or undereducated (Ebrahimi 2006 as cited in Hashemi et al. 2014). Smallholder farmers with farms that are less than 10 ha in size represent about 78 % of farmers, and they have particularly low income. Many smallholder farmers are subsistence farmers (about 75 % of the market supplies come from farms that are greater than 10 ha in size; Keshavarz et al. 2005). The rural populations have no/limited off-farm job opportunities in rural areas. During drought conditions in particular, there is likely to be increased unemployed farmers in urban areas (Alibaygi and Karamidehkordi 2009; Ghanbari et al. 2012; Keshavarz et al. 2013; Khatir and Rezaei-Moghaddam 2014; Madani 2014). These observations suggest that insufficient capacity to undertake transformational reform exists at the individual scale in Iran.

Agricultural transformation in Iran is unlikely to be supported at other scales. Iran has been continuously under international sanctions since the revolution making self-sufficiency a must for the state. It is likely that the government will try and keep the status quo and resist any call for transformation, at least in the short term. In addition, there is no policy intervention that considers off-farm migration for farmers as a type of adaptation to environmental change (Adams and Adger 2013). Instead, government interventions have encouraged rural populations and farmers to stay within the countryside [although with low success] (Sarvarzadeh and Mohammadi 2013). Even if off-farm migration were encouraged, it is unlikely that farmers would take advantage of any incentives, regardless of the economic imperatives. The occupational attachment that farmers are likely to have to farming, and their attachment to their farm lifestyle and "place" may mean that social drivers to remain farming on their farm are stronger than economic drivers, even though remaining on farms may be considered irrational from an economic point of view (Marshall et al. 2014; Adams 2015). In sum, the agricultural situation in Iran is likely to continue as is, on its current trajectory, for the foreseeable future.

As a conclusion of Discussion and Off-farm-based livelihood period (Sects 5.5 and 5.6), the transition prior to 1962 to the 1962–1979 period was triggered by a loss of resilience of the main institutions mediating the relationship between resource and resource users and continued with implications for the resources' resilience and farmers' livelihoods. Meanwhile, looking at changes that occurred after the revolution trying to improve farmers' livelihood mostly by a sole focus on agricultural activities and encouraging using the resources from a vulnerability perspective would overlook to explore the trends in the resources' resilience.

From the resilience perspective, recent droughts in the country may provide some windows of opportunity to move toward a sustainable adaptation trajectory, but current responses are within a command and control logic, and are trying to keep farmers' livelihood systems within the current trajectory of development.

Critical features of the Iranian agro-ecological system may have been missed if either a vulnerability or a resilience approach had been applied to understanding these shifts in the Iranian farming system. In general, the farming system has experienced major increases in agricultural production since the implementation of land reforms started in 1962. Since 2000, however, the system has shown high sensitivity to climate change. "Command and control" policies were common during this period (Engle et al. 2011). A resilience perspective focused on resource use and overlooks changes in farmers' economic situation (e.g., farmers' income and income inequality), social structure, power balance, homogeneity, institution's resilience, etc.

6 Conclusions

The main purpose of this paper was to combine farmer-focused and agro-ecosystem-focused approaches to better conceptualize sustainable adaptation to future climate change within an agro-ecological system, using Iran as a case study.

We showed that combining the two approaches can have far-reaching implications for farmers' adaptation to future climate change knowledge, policy, and practice since one approach aims to decrease farmer vulnerability and the other approach aims to build resilient agro-ecosystems (Table 1).

The integration of the two approaches means that it is possible to conceptualize how Iranian farmers, at least, can move toward a sustainable adaptation trajectory to future climate change. More exactly, our approach can build the resilience of farmers to future climate change by both minimizing their vulnerability and enhancing their resilience (Table 1).

Our integrative approach provides important insights for both research and policy on adaptation to climate change. Vulnerability research with its focus on farmers and social subsystems, among others, can contribute to adaptation, ensuring that what ultimately is sustained in the future is farmers themselves. In addition, resilience research can provide insights into transformation and can contribute to the sustainability of such adaptation.

In summary, we conclude that the demise of the community-based land tenure system in Iran, along with the government's command and control policy to maximize use of resources and ensure food self-sufficiency, and rapid population growth, resulting in heavy resource degradation, have significant implications for dealing with variability and changes in climatic conditions. In other words, Iranian farmers' current and future vulnerabilities (resilience) to changing climatic conditions are resulted from a multitude of factors rooted and developed in the past and in multiple spatial scales (from local to international). As a result, future climate change, as one of many stressors threatening farmers' livelihoods, will only exacerbate their present situations. In addition, we emphasize at this point that climate change impacts currently seen in the country indicate how close are the Iranian farming system/farmers to lost their general resilience [to all kinds of stressors (Folke et al. 2010)]. This may provide a window of opportunity for farmers to transform their on-farm-based livelihood system in the long-term, although transformation would not be easy to implement in the current Iranian context. Remembering that there are 78 million people who live in Iran and rely on the products from agriculture; that there are international sanctions against the country requiring Iran to be more or less self-sufficient; and the impacts of climate change are likely to become more severe, the future of agriculture in Iran is uncertain. However, the country could move toward sustainable adaptation to future climate change if insights from both vulnerability and resilience approaches could be considered in visioning the future for Iranian agriculture and in its policy development.

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