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Research Paper

Realistic evaluation of crop water productivity for sustainable farming of wheat in Kamin Region, Fars Province, Iran

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ABSTRACT

Currently, the economic wheat production faces severe challenges due to an increasing number of droughts. In an effort to enhance yields, most arid and semi-arid areas increase the water volume used for irrigation and cultivation of wheat, resulting in an intensified pressure on water resource systems. Therefore, it has become increasingly important to determine the required water volume per unit area in relation to expected wheat performance. However, such an estimation of relevant performance factors has been difficult due to unpredictable water supply capacities and the lack of reliable estimates for the demand of water. The potential crop water productivity (PCWP) defined in this study was comparing with its actual value has which obtained from field measurements based on a new approach of risk quantification. Using this comparison of water use, the management coefficient was estimated, and the production reliability of wheat was calculated.

Based on these factors, farms that had competently adapted their management in line with climate change and water availability were selected. The results reveal that only 26 of a total of 666 wheat farms which evaluated for this case study have had reliable crop water productivity and could thus be used as models for other farms. The results showed 100% increasing in CWP with a 27% reducing in hydro-module on these farms, in which case more than 34% will be reduced the groundwater withdrawal. Therefore, the sustainability of groundwater resources would be better, whereas the benefit cost ratio of the whole region and the superior farms has no significant difference. The amount of water that these farms use and the resulting yield can be a suitable reference to determine the expected yield and required water volume per unit area.

1. Introduction

Intensifying agriculture to increase the food supply of the ever-growing population with only an economical and income focused point of view has been creating excessive pressure on environmental resources. This pressure has especially been raised due to climatic changes, associated with an increase of droughts in arid and semi-arid regions. These phenomena lead to soil degradation, increase soil and water salinity and as a result compromise the regions agricultural stability (Gao et al., 2017). Therefore, it is necessary to determine sustainable conditions for stable crop and agricultural production. It is worth mentioning that quantifiable indicators are essential to assess stable conditions.

Since measuring the intricate situation of any agricultural system is a very complex endeavor, agricultural sustainability is not precisely measurable (Pretty, 1995). Acquisition and integration of spatially and temporally significant and thus suitable indicators, is a general problem in the assessment of farming practices. To predict system trends, it is necessary to select suitable and specific indicators (Pretty and Thompson, 1996; Brandi et al., 2017).

The efficient operation and management of an irrigation system plays an important role in the sustainability of irrigated agriculture (Kumar and Singh, 2003; Kam and Ding, 2017). Crop water productivity (CWP) is a measure for the performance of irrigation systems and describes the efficiency of the physical system and operational decisions that deliver water from a water source (Irmak et al., 2011). Reliable evaluation of crop water productivity is necessary to improve system management (Small and Svenddsen, 1990; Clemmens and Molden, 2007), to determine the overall state of the system (Bhadra et al., 2010; Pereira et al., 2012) and to detect the

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elements that cause problems in the water resource system (Vos, 2005; Shakir et al., 2010).

To quantify the gap between potential and actual crop water productivity, it is necessary to strategically compare the farm and global crop water productivity. This calls for a quantification of the vulnerability of the water resources system (Diwekar, 2017). Most studies in the arid and semi-arid area have been focusing on the utilization of soil and water resources (Liu et al., 2001; Arfanuzzaman and Rahman, 2017). Few studies focused on water sufficiency, while providing a soil suitability analysis (Wang and Lou, 2001). Evaluating farming practices with an interdisciplinary approach that encompasses environmental, economic and socio-institutional aspects is relatively new; and also, limited efforts have been made to evaluate farming practices via location-specific indicators and their thresholds.

CWP is a function of many diverse factors such as atmospheric water vapor pressure deficit, soil fertility, irrigation, and pest and disease control. Any management factor that increases crop yield (including economical aspects) also increases CWP, making it less responsive to changes in these factors, than yield (Liu et al., 2007). However, how to improve water productivity is a rather complex question, given the agronomic, hydrologic, and socio-economic conditions of the arid and semi-arid area (Deihimfard et al., 2007).

Climate change affects water resources and crop productivity and farmers cannot adapt their management strategy accordingly. As a result, the physical and chemical properties of water and soil are often transformed. Consequently, CWP is not the same for all farms and can even change annually. The CWP value for each farm is calculated by dividing the measured yield per unit of available water. These two factors possess strong spatial and temporal variability and are the reason that CWP has been an obscure value with a range of variation created by climate change and farm management. This unpredictability needs to be considered and modeled when CWP is applied as an indicator.

Similar to the definition of sustainability by Tamara and Francesco, CWP could be defined as an appropriate practice of natural resources by considering present and future resource consumption (Menichini and Rosati, 2013). Thus, energy producers (such as farms) need to generate integrated performances and balance between economic and environmental lines to satisfy inter-generational equity needs (Modaresirad et al., 2017).

Our study introduces an approach to assess the reliability of on farm crop water productivity, which is essential for identifying key issues to improve water management. Here, we compare the potential CWP with actual values obtained from field measurements. This comparison of unpredictable conditions is based on a novel approach to quantify hazard and leads to a management coefficient of water use that is useful to understand the behavior of the farmer, while taking general agricultural trends into account. Analyzing the results leads to insights into potential improvement methods and enable the development of water management policies that enable planners to improve the sustainability of water resources systems.

Evaluation of the reaction of individual farmers to improve the sustainability of water resources systems would be ideal, but is not easy because of time and investment limitations (Hua et al., 2016). Classification of farmers to homogenous groups of farm-types and evaluation of the reaction of each farm-type instead of individual farmers is a way which can be used for solving this problem. Our study attempts to enhance our understanding of the factors for differences in agricultural productivity and sustainability. The main objective was to assess the performance of irrigated wheat farms with a focus on the analysis of cross-sectional differences of CWP and to determine the potential productivity in the Kamin Region, Fars Province, Iran. We used a data base of 666 irrigated wheat farms located in this region to develop a model to simulate the spatial distribution of yield and the quantifying hazard for the use of available water.

In the classification of farms based on soil and water characteristics, the difference in yields in each class is significant, but the range of variations in each class is not the same in the whole region. On the other hand, the mean of each class has a significant difference and indicates the role of the basic production factors in yield. But in this study, there is a view point that due to the management of farmers, in each class where water and soil conditions are the same, there is a significant difference in yield. Hence, the management coefficient we introduced in this study can show the role of these factors on sustainable water use. It is worth noting that the difference between locally and globally calculated values of CWP could be caused by the changing climate of recent years. Due to climate change, the water volume has been receding and irrigation has been increased to maintain production. Therefore, management plays a role in increased productivity in recent years. Weakness of production management caused intensification of resources pressure and yield sustainability.

1.1. Reliability and hazard quantification

Risk quantification is the next step following problem formulation and the analysis of different uncertainties that potentially cause a risk of failure (risk identification). Quantifying risk is of key importance in agriculture because simulation, prediction and engineering design are all based on quantitative rather than qualitative concepts (Ganoulis, 2009; Mishra et al., 2012). By definition, risk analysis relates to uncertainties and any quantification of risks should be based on methodologies that take uncertainties into account. Two main theoretical approaches are available for doing so: (i) the probabilistic approach and (ii) the fuzzy set theory. When loads and resistances are assumed to be constant at a given time, static reliability analysis is considered first.

Although, such a stochastic approach is relatively well established, fitting probability laws and analyzing dependencies between random variables needs large quantities of data, which are not always available. If load and resistance are assumed as independent, direct integration may be applied to quantify risk and reliability. Available data may be used to estimate extreme values and risk of accidents, such as the hydrologic risk and management behaviors.

In the present study, we consider loads and resistances to be time-independent, positive scalars, applied on a single component of a system. Time-independency is a necessary assumption that enables direct integration for risk quantification. This approach is generally known as static reliability analysis.

Unsteady system or reliability should be considered in situations where loads and resistances vector with several components. On-farm production with unsteady resources is also a system with several management components. Therefore, the reliability of agricultural systems under hazard should be evaluated using the stochastic approach.

Here, we consider the load or exposure λ as a random variable L. In this case uncertainties are associated with an estimation of L and are quantified via probabilistic methods. The resistance or capacity r is expressed with the same unit as exposure. In uncertain cases, probabilistic methods may be used to describe resistance as the random variable R. If both λ and r are positive random variables and probabilistic methods are utilized to quantify risk (Fig. 1), we can compute the risk pF as follows:

$$pF = p(L \geq R) = \int_0^\infty F_R(l) f_L(l)\, dl \qquad (1)$$