Ecological Indicators 48 (2015) 49–54

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

A novel method for quantitatively evaluating agricultural vulnerability to climate change

Zhiqiang Dong[a,b], Zhihua Pan[a,b,*], Pingli An[a,b], Liwei Wang[a,b], Jingting Zhang[a,b], Di He[a], Huijie Han[a], Xuebiao Pan[a,b]

[a] College of Resources and Environmental Science, China Agricultural University, Beijing 100193, China
[b] Key Ecology and Environment Experimental Station of Ministry of Agriculture for Field Scientific Observation in Hohhot, Wuchuan, Hohhot 011705, China

ARTICLE INFO

Article history:
Received 25 February 2014
Received in revised form 14 July 2014
Accepted 23 July 2014

Keywords:
Climate change
Agriculture
Vulnerability
Sensitivity
Adaptive capacity
Exposure degree

ABSTRACT

Climate change has affected all aspects of human societal development as a global problem, especially agriculture, which is closely related to human survival. Evaluating vulnerability can be helpful in assessing the impact of climate change and analyzing the effectiveness and adaptive degrees of different countermeasures to provide a reliable basis for addressing climate change. However, determining how to quantitatively evaluate vulnerability is a difficult problem and a pressing question. We propose an objective and quantitative assessment method for agricultural vulnerability under climate change according to the Intergovernmental Panel on Climate Change's definition of vulnerability and a framework of sensitivity, adaptive capacity, and exposure degree. We explain the practical and objective attributes of this method using Wuchuan County in Inner Mongolia as an example. This assessment method can clarify the effects of climate change on agriculture and effective countermeasures, as well as contribute to the sustainable agricultural development.

1. Introduction

Climate change is a global phenomenon and a significant problem (Schmidt et al., 2013). Currently, climate change is attracting more attention as an issue to consider, a scientific issue to study, and an environmental policy issue to debate endlessly (Sioshansi, 2005).

Recent researches concluded that "Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850" (IPCC, 2013). In the Northern Hemisphere, the period from 1983 to 2012 was likely the warmest 30-year period in the last 1400 years. Averaged over the Northern Hemisphere's mid-latitude land areas, precipitation has increased since 1901. For other latitudes, area-averaged long-term positive or negative trends for precipitation were not significant (IPCC, 2013).

The negative factors brought by climate change have become an important limiting factor for agricultural development, especially the increasingly frequent droughts, floods, and soil erosion. The vast majority of African, Asian, European, and Latin American countries have experienced a substantial reduction in food production. Agricultural production is facing an unprecedented threat that is becoming more serious as climate change develops (IPCC, 2001). Some parts of China even faced non-production of food crops year after year (Xiao et al., 2007).

In some countries, climate trends offset a substantial amount of the increases in average yields due to technology, carbon fertilization, and other factors (Lobell et al., 2011). Although some studies have shown that certain effects of climate change would be positive to the yields of some kinds of crops, these positive effects would be counteracted by the negative effect of increasing temperatures (Rosenzweig and Parry, 1994; Parry et al., 2005; Long et al., 2006; Lobell and Field, 2007).

As the population continues to rise, adequately and effectively supplying global food requirements is becoming a major problem for humans to solve. How to adopt reasonable strategies that adapt to local conditions and how to optimize planting patterns under new agricultural technology conditions are receiving more attention. Solving these problems will allow us to continue to use climate resources reasonably and efficiently, and realize the sustainable development of agriculture under conditions of relatively high production. However, food security cannot be guaranteed in areas that lack adequate and effective adaptation measures (Lobell et al.,

* Corresponding author at: China Agricultural University, College of Resources and Environmental Science, No. 2 Yuanmingyuan West Road, Haidian, Beijing, China. Tel.: +86 10 62733839.
E-mail address: panzhihua@cau.edu.cn (Z. Pan).

http://dx.doi.org/10.1016/j.ecolind.2014.07.032
1470-160X/

2008). In addition, more countries and regions cannot analyze the impact of climate change due to lack visual and quantitative assessment tools, which prevents them from taking effective measures in time to adapt to climate change.

Vulnerability assessment is a powerful analytical tool for describing states of susceptibility to harm and powerlessness and for guiding normative analysis of actions to enhance well-being by reducing risk (Adger, 2006). It's helpful to assess the impact of climate change and analyze the effectiveness and adaptive degrees of different measures to provide a reliable basis for addressing climate change.

Detecting the impacts of climate change on agriculture and evaluating vulnerability is important for the growing population to provide food security countermeasures. Therefore, agricultural vulnerability to climate change has become one important key to study the effect of climate change on agriculture. This paper proposes a method for quantitative evaluation of agricultural vulnerability to climate change. This method has great significance in developing initiatives for adapting to climate change, taking effective countermeasures, and contributing to the sustainable agricultural development.

2. Vulnerability and its evolution

The concept of vulnerability originated from the study of natural hazards (Janssen et al., 2006) and was introduced gradually to the field of the impacts of climate change on systems.

More than 30 years ago, vulnerability was expressed as the degree to which systems show the extent of a negative response to a disaster (Timmerman, 1981). Vulnerability was linked with concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk (Liverman, 1990). Some researches extended it into exposure, sensitivity, coping capacity, criticality, and robustness (Fussel, 2007). Currently, vulnerability is used in climate change research to emphasize the result of a system facing unfavorable disturbances or disasters (Li et al., 2008). For example, vulnerability is the extent of damage that a system or subsystem may suffer when exposed to disasters, disturbances, or pressures (Turner, 2003).

Previous Intergovernmental Panel on Climate Change (IPCC) assessment reports gave a corresponding definition and interpretation of vulnerability. Especially in the third IPCC assessment report, "Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes, is a function of the character, magnitude and rate of climate change and variation to which a system is exposed to, its sensitivity, and its adaptive capacity" (IPCC, 2001).

According to the IPCC assessment reports, vulnerability is a framework of sensitivity, adaptive capacity, and exposure degree (IPCC, 1995, 2001, 2007). In the third IPCC assessment report, sensitivity is defined as how deeply a system is affected by climate-related stimuli, whether adversely or beneficially. Adaptive capacity is defined as a system's ability to adjust to climate change (including climate variability and extremes), moderate potential damages, take advantage of opportunities, or cope with consequences. But the third assessment report did not provide a specific definition of exposure degree. Based on the concept of reflecting the characteristics of actual problems and circumstances, we developed the following definition of exposure degree, which is the range of subjects exposed to influencing events such as climate change and climate variability. Therefore, we established the conceptual model of vulnerability assessment as

$$\text{Vulnerability} = \frac{\text{sensitivity}}{\text{adaptive capacity} \times \text{exposure degree}} \tag{1}$$

How to use the above model is the next step. We should find a quantitative method to assess sensitivity, adaptive capacity, and exposure degree.

3. A quantitative approach for evaluating agricultural vulnerability

First, we suggest that agricultural vulnerability is the degree of impact to agriculture caused by climatic factors that change under climate change.

Vulnerability assessment should help identify the impacts of climate change at different levels (Fellmann, 2012), so second, we introduce the concepts of unit vulnerability and regional vulnerability to express the vulnerabilities at different levels. Unit vulnerability is the vulnerability for a crop in a unit area, which is the crop's basic attribute under climate change. Its calculation is shown in the following equation:

$$\text{Unit vulnerability} = \frac{\text{sensitivity}}{\text{adaptive capacity}} \tag{2}$$

Corresponding with unit vulnerability, regional vulnerability is extending from the unit area to a regional scale, shown as Eq. (3). Thus, the unit vulnerability and exposure degree is the magnitude and extent of vulnerability, respectively.

$$\text{Regional vulnerability} = \text{unit vulnerability} \times \text{exposure degree} \tag{3}$$

Third, we chose factors that could quantitatively evaluate every component that constitutes vulnerability. In agriculture, we focus most on yield change. Yield change can reflect the impacts of climate change on agriculture more intuitively, so we chose yield as the index for agricultural vulnerability assessment.

Generally, yield can be decomposed into trend yield, fluctuant yield, and random error. Trend yield reflects the crop yield component from productivity developing level for a long period. Fluctuant yield reflects the crop yield component affected by the fluctuation of climatic elements, and is also called the climate yield. Random error is the yield affected by other random factors, which is micro and can be ignored.

The computational formula for yield is

$$Y = Ya + Yc \tag{4}$$

where Y is the crop yield (expressed by the per-unit area yield, kg/hm^2); Ya is the crop trend yield (the crop technology yield of itself and artificial adaption, kg/hm^2); Yc is the fluctuant yield (the yield affected by the climatic factors, referred to as the climatic yield, kg/hm^2).

Change implies the difference between two different time periods, so the assessment time should be defined in the impact assessment of climate change. So fourth, we define the concept of the basic period and the study period. They are the two fundamental times to research agricultural vulnerability to the influence of climate change. The basic period is before climate mutated whose climate environment is relatively stable. During the basic period, crop yield affected by climatic fluctuant yield change expresses the fluctuation change around the trend yield. The study period is after climate mutation, the impact of climate change is the most outstanding major uncertainty, so this period is also called the changing period. Crop yield in the study period expresses adaptive change around the climatic yield.

Fifth, we introduce the quantitative expressions of vulnerability components. Sensitivity is expressed by the increase or decrease in the amount of crop yield with climate change, called sensitive