Agriculture, Ecosystems and Environment 230 (2016) 221–230

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

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

Indicator-based evaluation of spatiotemporal characteristics of rice flood in Southwest China

Jianying Yang[a], Zhiguo Huo[a,b,*], Li Wu[a], Tianying Wang[a,b], Guixiang Zhang[a]

[a] State Key Laboratory of Severe Weather (LASW), Chinese Academy of Meteorological Sciences, Beijing 100081, China
[b] Collaborative Innovation Center of Meteorological Disaster Forecast, Early-Warning and Assessment, Nanjing University of Information Science & Technology, Nanjing 210044, China

ARTICLE INFO

Article history:
Received 15 September 2015
Received in revised form 2 June 2016
Accepted 6 June 2016
Available online xxx

Keywords:
Risk indicators
Risk zoning
Precipitation
Trend analysis

ABSTRACT

Frequent occurrences of extreme rainfall events create severe rice floods. To prevent rainfall-induced rice floods and reduce potential losses, it is important to establish meteorological evaluation indicators and precisely understand the spatiotemporal characteristics of rice floods, to provide support for rice flood monitoring, prevention, and mitigation. In this study, precipitation, disaster and phenophase data of rice in Southwest China (Sichuan, Chongqing, Guizhou, and Yunnan provinces) were integrated to establish meteorological evaluation indicators of single-cropping rice floods, and the rice flood index (RFI) from 1961 to 2012 was thereby estimated to gain detailed information on rice flood disaster characteristics in that region. The threshold of rice flood in the transplanting-tillering stage was 120, 130, and 150 mm for 1, 2, and ≥3 d, respectively. This was 150, 160, and 180 mm for the jointing-booting stage, and 170, 200, and 230 mm for the tasselling-maturity stage, respectively. Identification results by rice flood level were found basically consistent with the historical occurrence of rice flood disasters, with 66.7% of historical records strongly consistent with the flood level assessment, and calculated errors of all validation data were within one level. High RFI was faced by the transplanting-tillering stage, followed by the jointing-booting and transplanting-tillering stages. High-RFI (>1) areas in the whole rice stage were southern and northeastern Yunnan, southern Guizhou, plus Chengdu, Meishan, and Deyang in Sichuan Province. Regional RFI in the whole stage showed a negative trend, with slope 0.0246 ($R^2 = 0.1523$). RFI at 120 stations, or 62.83% of all stations, decreased over the whole rice stage, while RFI increased at 70 stations, mainly in Guizhou, northeast of Sichuan.

1. Introduction

Rainfall-induced floods are frequently agriculture disasters, and often cause serious crop production losses (Schmidhuber and Tubiello, 2007). Heavy rainfall events and their consequent floods are expected to occur more frequently, at different times and locations, and become more catastrophic (IPCC, 2013), with extreme precipitation events increased at the rate of 6% per 10 years (Alexander et al., 2006; Dore, 2005). It is of great merits to investigate the relationship between precipitation extremes and crop damage, and explore meteorological evaluation indicators to prevent rainfall-induced floods and reduce potential crop losses as much as possible.

Impacts of flood on agriculture and hence food security have received increased attention in academic circles during recent decades (Bandara and Cai, 2014; MacDonald, 2010; Zhang et al., 2012). Indicators based on hydrological and meteorological data have been used to predict and monitor floods. For example, Zhang et al. (2015) analyzed flood-induced agricultural loss at province scale across China and impacts from climate indices such as ENSO, NAO, IOD, PDO and AMO. Chau et al. (2013, 2015) indicated that 1:10-, 1:20-, and 1:100-year floods may cause respective agricultural losses of 27%, 31%, and 33%, and economic losses of 22, 115, and 147 billion Vietnamese Dong (VND). To assess the impact of weather disasters on agriculture, one must link two fundamental aspects. First is the disaster itself, i.e., the destructive power of the disaster weather event. Second is the characteristics of the agricultural system affected. Agriculture is a complex system, and influence of flooding varies with the crop. To grasp actual variability and trends of floods in agriculture, it is better to restrict

* Corresponding author at: No. 46, Zhongguancun South Street, Haidian District, Beijing 100081, China.
E-mail address: huozhigg@camscma.cn (Z. Huo).

http://dx.doi.org/10.1016/j.agee.2016.06.008
0167-8809/

a study to a target crop, linking it with the availability of crop data. Currently, agro-flood studies mainly focus on the whole agriculture, and research into crop flooding is rare.

Rice is recognized as generally well-adapted to flooding, but excessive flooding may result in a rice flood (Ram et al., 2002). Rice flood is generally defined as the deterioration in energy metabolism and photosynthesis of rice caused by water failing to discharge from farmland timely, thus resulting in casualties and reductions in rice productivity. Yield losses from floods can be from 10% to 100%, depending on water depth, duration of submergence, and age of rice (Das et al., 2009; Gautam et al., 2015). Current research on rice flood largely concentrates on waterlogging experiments in the field (Anandan et al., 2015) under controlled duration and depth, providing basic information such as morphology, physiology, yield and yield components, and recovery mechanisms of rice under submersion (Kawano and Ito, 2009; Ito et al., 1999; Singh et al., 2001; Sarkar et al., 2006). However, such experimental evidence has limitations for effective rice flood monitoring and risk assessment because the availability of accurate data of inundation duration and depth are limiting factors (Abdalla and Niall, 2009; Chau et al., 2013). Relationships between rice productivity and rainfall indices have been explored by researchers, providing basically information of frequency and magnitude of extremes events and its influence on agricultural (Subash et al., 2011). Indicators of flood such as monthly, seasonal, and yearly precipitation, however, show serious limitations for timely pre-, during, and post-flood damage data acquisition because rice flood events are always associated with certain extreme precipitation processes (Goswami et al., 2007). Moreover, the capacity to survive submersion depends not only on certain environmental factors but also on the growth stages that plants have evolved in response to particular flood-prone environments.

Southwest China is characterized by increasing precipitation extremes, thereby increasing the frequency of floods (Zhang et al., 2015). Flooding in that region is common and often causes considerable damage, with devastating flood events have been witnessed in the past decades (Editorial board, 2007). Single-cropping rice is the main crop in Southwest China, with ~4.67 million hm^2 planted there, accounting for over 30% of the total cultivated area of single-cropping rice in China (NBSC, 2010). The growth period of single-cropping rice in the region is May through October, which corresponds well with the temporal distribution of rainfall. This indicates that the overwhelming majority of flood disasters for rice occur as a result of rainfall. Therefore, establishing meteorological evaluation indicators and developing a better understanding of rice floods provide insight into adaptation strategies for planners and managers, enabling assessment of rice flood intensity and development of improved rice flood protection strategies.

Documentary evidences of historical flood events may greatly contribute to the flood studies (Kjeldsen et al., 2014; Llasat et al., 2010; Ng et al., 2015). Incorporating learning and feedback from disaster experience is crucial to hazard management (Plate, 2002). Damage and methodology data have been coupled to identify the rainfall parameters that can be used as risk indicators and adjust the threshold values above which losses occur (Petrović et al., 2015). Based on daily precipitation from 1961 to 2012 at193 meteorological stations, historical disaster records and phenophase data of rice in Southwest China (Sichuan, Chongqing, Guizhou and Yunnan), historical rice flood events were represented and the objectives of this study are as follows: (1) establish evaluation indicators of flooding related to single-cropping rice; and (2) estimation of rice flood risk according to rice flood evaluation indicators, to obtain detailed information on the characteristics of rice flood disaster in Southwest China.

2. Materials and methods

2.1. Study area

Southwest China (Fig. 1a) is composed of the provinces of Sichuan, Yunnan, Guizhou, and the prefecture of Chongqing. There is a farmland area of 19,000 thousand hm^2, at elevations from 150 to 5000 m. Southwest China embraces major branches of the upper Yangtze and Pearl rivers, and several transboundary rivers. It is a flood-prone region, owing to the combined effect of a subtropical/tropical climate and mean annual precipitation of 1000–2000 mm. Because of the impact of the monsoon troughs and tropical cyclones, the annual distribution of rainfall is not uniform. Rain concentrates from June through September, typically accounting for more than two thirds of annual rainfall (Du et al., 2013). Although the number of rainy days has decreased significantly over almost all southwestern China (Gemmer et al., 2011), the number of extremely heavy rains has increased in most of the region (Zhai et al., 2005). Owing to its geological, geomorphological, and

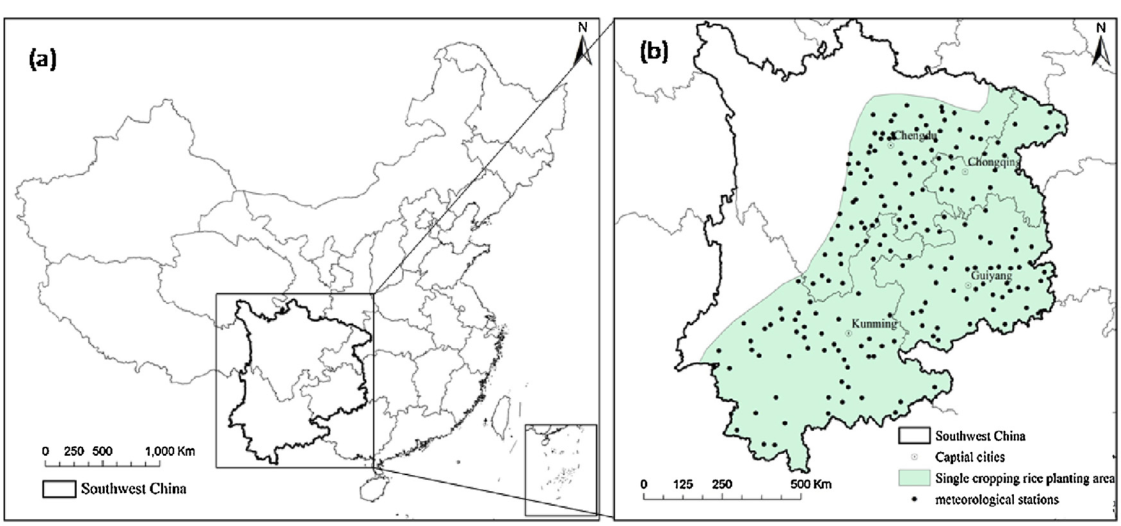

Fig. 1. The inset map shows the location of the Southwest China, single cropping rice planting area and meteorological stations.