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Indicators Establishment and Risk Assessment of Double-cropping Rice Flood Disaster in Hunan Province

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16.05.20

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- Results
  - Flood level indicators of double-cropping rice in different growth stages
  - Temporal-spatial distribution of double-cropping rice flood disaster
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- Discussion

Background

- Flood is a main natural disaster on agricultural production in China, especially in rice production in the middle-lower Yangtze Area.
- Hunan located in the middle of Yangtze Area. Rice is the major grain crop of Hunan. Flood occurs in every growth period of early and late rice.

- **Flood disaster is closely related to the heavy rain**

  Index system: rainfall (daily, ten-day, month, season, annual), precipitation days, drought index (Z&K index) (Kite, 1977; Tian *et al*., 1989; Ahn&Choi, 2013).

  Hazard bearing body: the whole agriculture&forestry (mainly); single crop (basicly only field experiment)

Rice flood disaster research

- Remote sensing: affected area monitoring, damage assessment (Sakamoto *et al*., 2009； Son *et al*., 2013)
- Ground meteorological data: annual heavy rain and torrential rain days and rainfall (Li *et al*., 2013), effective rainfall of rainstorm (Chen *et al*., 2010)
- Field control experiment:

Divide into growth stages to take further study (FAO);

The sensitivity of rice in different cropping systems and different growth stages is different to flood disaster (Li *et al*., 1996; Peng *et al*., 2001; Li *et al*., 2004； Ning *et al*., 2013; Wu, 2013)

- Plant physiology: Submergence stress experiment

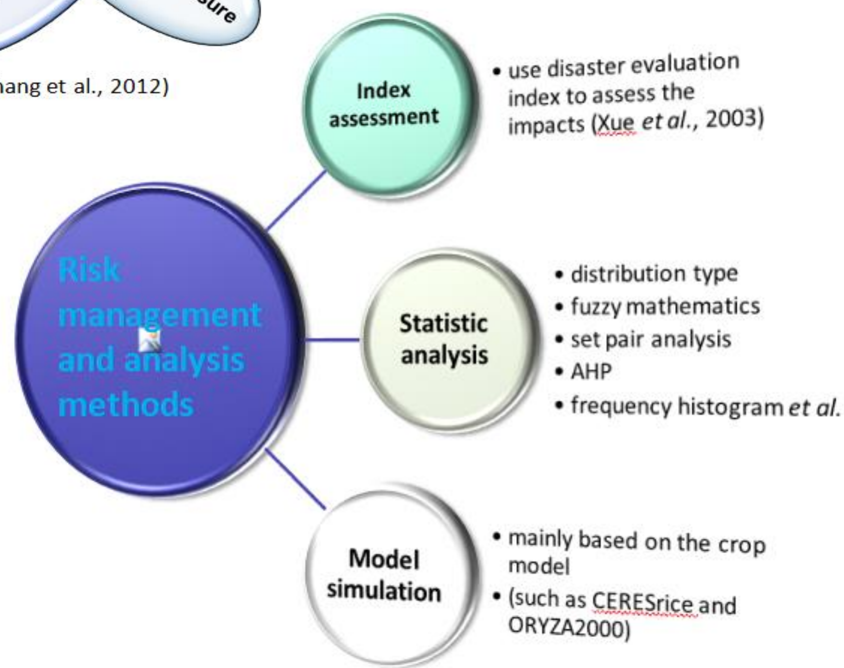
The contents of N and K increased and decreased, respectively (Reddy *et al*., 1985); G-6PD activity increased (Ricard *et al*., 1991)

Research progress of risk assessment

- Theory of disaster forming mechanism: Hazard factor; disaster-forming environment; hazard-affected body; regional natural disaster system
- Disaster risk management:

(Maskrey *et al.*, 1989; Smith *et al*,. 2013) (Okada *et al*,. 2004) (Zhang et al., 2012)

Risk management and analysis methods



Methods

- **K-S test** (probability distribution characteristics)
- **Linear trend analysis** (occurrence trend of rice flood)
- **Linear sliding average method** (separate the trend yield)

  construct Linear trend equation:

$$y_i(t) = a_i + b_i t$$

$i=n-k+1$;

k: step of equation;

n: number of samples.

$$\bar{y}_j(t) = \frac{1}{r} \Sigma_{j=1}^{r} y_i(t) \;\; (j = 1,2, \dots, r)$$

- **Synthetic weighted mark method** (calculate targeted value)

$$M = \sum_{i=1}^{n} A_i w_i$$

M: targeted value;
A_i: value of index i;
w_i: weight of index i.

– Entropy method (calculate targeted value)

construct nondimensionalize matrix *R*:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1j} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2j} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots & & \vdots \\ r_{i1} & r_{i2} & \cdots & r_{ij} & \cdots & r_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mj} & \cdots & r_{mn} \end{bmatrix}$$

define the entropy of index *j*:

$$S_i = -\frac{1}{\ln n} \Sigma_{j=1}^{n} f_{ij} \ln f_{ij}$$

$$f_{ij} = \frac{r_{ij}}{\Sigma_{j=1}^{n} r_{ij}} \ (\mathrm{i} = 1,2, \dots, m)$$

the entropy weight of index *j*:

$$w_i = \frac{1 - S_i}{\sum_{i=1}^{m}(1 - S_i)}$$

– Non-dimensionalize

$$X_s = \frac{X_i - S_1}{S_2 - S_1}$$

$$S_1 = \frac{9 \times X_{min} - X_{max}}{8}$$

$$S_2 = \frac{9 \times X_{max} - X_{min}}{8}$$

– Cluster analysis -Ward's method (double-cropping rice flood risk zoning)

Flood level indicators of double-cropping rice in different growth stages

Data

– **Double-cropping rice area:**

Agricultural meteorological service manual

– **Daily precipitation data:**

68 national stations (1961-2010)

– **Phenophase data:**

17 agricultural meteorological stations in double-cropping rice area (1984-2015)

– **Historical disaster information:**

China Meteorological Disaster Authority (Hunan Volume)

China Meteorological Disaster Yearbook (2004-2007)

Hunan Climate Communique (2001-2010)

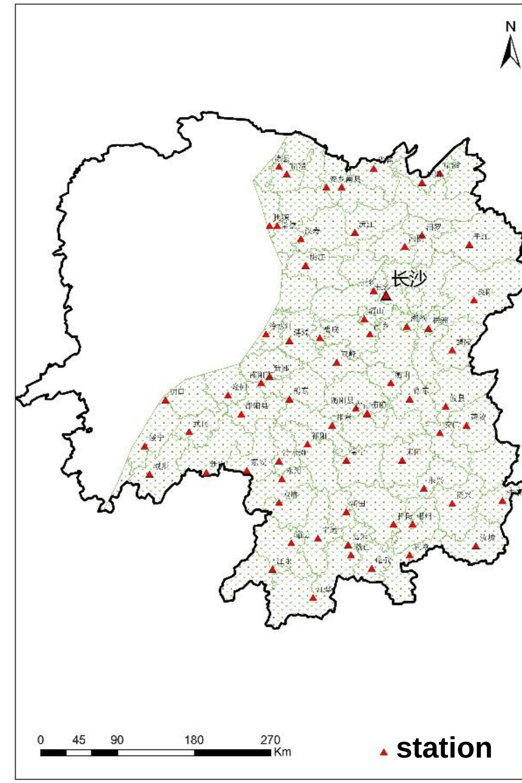
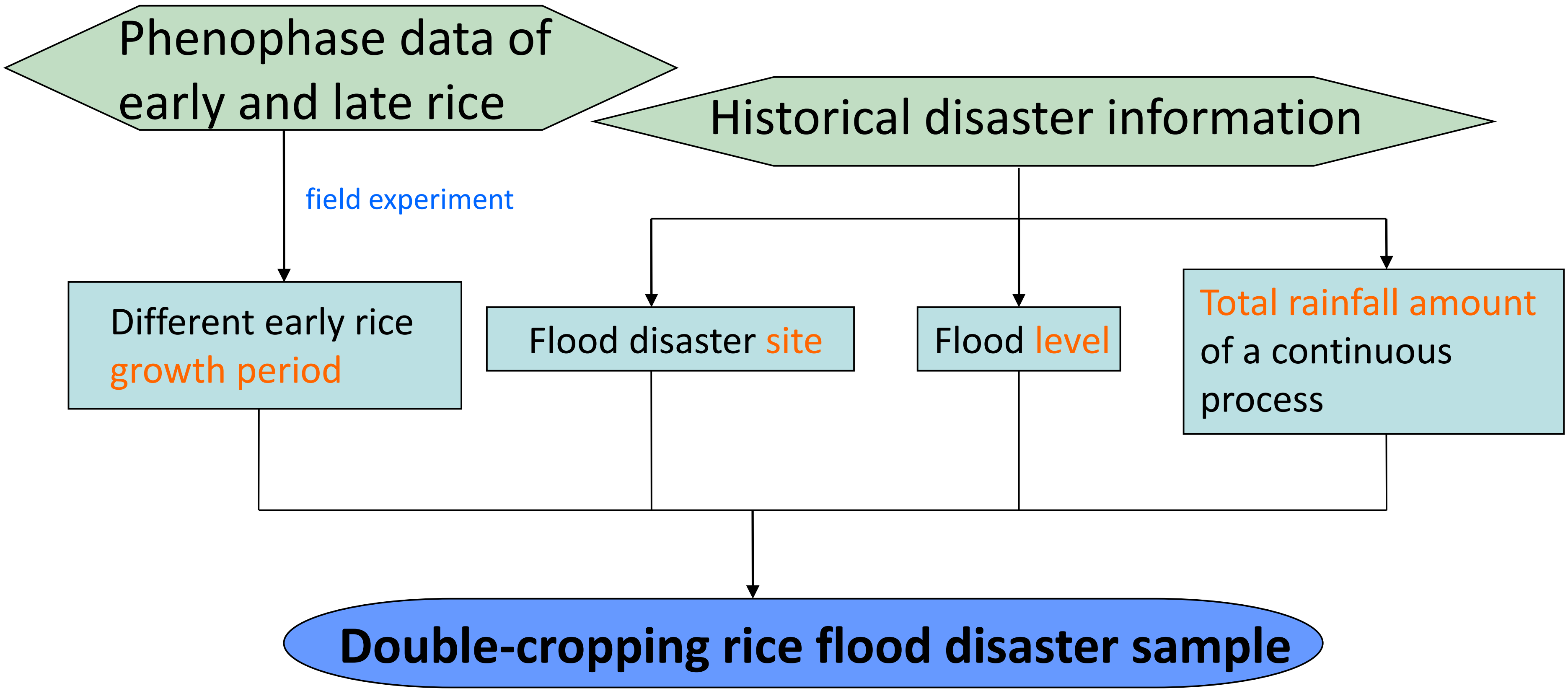


Fig. 2.1 Distribution of 68 meteorology stations in double-cropping rice area in Hunan

◆Build flood disaster sample



◆Build 9 flood sample sets, respectively

– **Take early rice for example:**

3 growth stages	3 flood disaster levels
Transplanting-jointing (5.3-6.14)	Light
Booting-blooming (6.15-7.4)	Moderate
Milk-maturity (7.5-)	Severe

– **Divided the late rice growth stages into 3 period in the same way**

transplanting-tillering stage (7.23-8.17)

jointing-booting stage (8.18-9.9)

blooming-maturity stage (9.10-)

Method

1. K-S test (probability distribution characteristics)

Normal, uniform, poisson, exponential, 4 types of distribution.

2. Student's t-distribution (determine the rainfall thresholds)

A better confidence interval estimation (95% or more) for the normal distribution population when sample observed data is incomplete (n<30).

◆Verify flood level indicator

- Set aside flood disaster samples in order to verify the indicator.
  - ✓ selection principal: random. Selected from different decade, different growth stages.
- To see if the flood disaster site and level (calculated based on the constructed indicators) in accordance with historical record.

Flood level indicators

– Using SPSS run K-S test

Table 2.2 Results of K-S test of double-cropping rice flood rainfall amount sample sets

(1) Early rice

Distribution		Transplanting-jointing			Booting-blooming			Milk-maturity		
		light	moderate	severe	light	moderate	severe	light	moderate	severe
Normal	Z value	0.879	0.545	0.637	0.980	0.626	0.500	0.577	0.449	0.614
	P value	0.423	0.927	0.811	0.292	0.828	0.964	0.893	0.988	0.846
Uniform	Z value	2.462	0.862	0.823	1.631	1.781	0.736	0.652	0.997	1.187
	P value	0.000	0.447	0.507	0.010	0.004	0.651	0.789	0.273	0.119
Poisson	Z value	3.330	1.823	1.676	3.281	1.530	1.547	1.391	1.087	0.893
	P value	0.000	0.003	0.007	0.000	0.019	0.017	0.042	0.188	0.403
Exponential	Z value	4.748	2.771	1.961	3.834	2.377	1.795	2.140	1.663	2.027
	P value	0.000	0.000	0.001	0.000	0.000	0.003	0.000	0.008	0.001

(2) Late rice

Distribution		Transplanting-jointing			Booting-blooming			Milk-maturity		
		light	moderate	severe	light	moderate	severe	light	moderate	severe
Normal	Z value	.790	.472	.875	.899	.510	.554	.792	.658	-
	P value	.560	.979	.428	.395	.957	.918	.558	.780	-
Uniform	Z value	2.085	.511	1.455	1.048	.659	.909	1.222	.937	-
	P value	.000	.956	.029	.222	.778	.380	.101	.344	-
Poisson	Z value	2.252	0.914	1.140	1.780	0.566	0.576	0.810	0.620	-
	P value	0.000	0.373	0.149	0.004	0.906	0.895	0.528	0.836	-
Exponential	Z value	2.971	1.852	1.411	2.041	1.719	1.240	1.665	1.341	-
	P value	.000	.002	.037	.000	.005	.092	.008	.055	-

– Using SPSS run Student's t-distribution and determine the rainfall thresholds of flood level indicators

Table 2.3 Double-cropping rice flood level indicators in Hunan Province

Early rice			Late rice		
Growth stages	**Flood level**	**Rainfall amount (mm)**	**Growth stages**	**Flood level**	**Rainfall amount (mm)**
Transplanting-jointing	**light**	129*≤R<154**	**Transplanting-tillering**	**light**	131*≤R<181**
	moderate	154**≤R<241**		**moderate**	181**≤R<251*
	severe	R≥241**		**severe**	R≥250+
Booting-blooming	**light**	135*≤R<170**	**Jointing-booting**	**light**	133*≤R<190**
	moderate	170**≤R<260**		**moderate**	190**≤R<264**
	severe	R≥260**		**severe**	R≥264*
Milk-maturity	**light**	145*≤R<190**	**Blooming-maturity**	**light**	137*≤R<209**
	moderate	190*≤R<295**		**moderate**	209*≤R<277**
	severe	R≥295**		**severe**	R≥277

+ refers to 'probability interval>0.90', * refers to 'probability interval>0.95', ** refers to 'probability interval>0.99'.

◻Indicator verification

Table 2.4 Verification results of double-cropping rice flood level indicators

Early rice			
Period	**Historical flood disaster site**	**Historical flood disaster level**	**Flood disaster site and level calculated by constructed indicators**
1967.6.30-7.1	Zixing	moderate	Zixing, moderate
1974.4.30-5.9	5 counties in north Hunan and Changsha	light	light flood in Lilin, Huarong, Pingjiang and Taojiang; moderate flood in Xiangyin and Liuyang
1988.6.16	Shaoyang county	moderate	Shaoyang county, moderate
1996.5.31-6.3	Yueyang area and 11 counties such as Taoyuan, Anxiang	moderate, parts severe	light flood in Nanxian, Yueyang, Taoyuan and Pingjiang;moderate in Lixian, Linli, Anxiang, Hanshou and Miluo;severe flood in Huarong and Linxiang
1997.7.20-7.23	Hanshou, Taoyuan and Lilin	light, parts moderate	light flood in Taoyuan and Taojiang; moderate flood in Hanshou

Late rice			
Period	**Historical flood disaster site**	**Historical flood disaster level**	**Flood disaster site and level calculated by constructed indicators**
1972.8.18-8.19	Chenzhou, Zixing, Guiyang, Lanshan, Yizhang, Guidong	Light, parts moderate	light flood in Zixing, Guiyang, Guidong, Lanshan; moderate flood in Chenzhou
1981.8.10-8.18	Huarong	light	Huarong, light
1991.9.7-9.8	Southeast of Hunan such as Guidong	Light, parts moderate	light flood in Guidong and Chenzhou; moderate flood in Rucheng
1995.8.1-8.3	Northeast of Hunan such as Linxiang, Miluo	Light, parts moderate	light flood in Miluo and Pingjiang; severe flood in Linxiang

Temporal-spatial distribution of double-cropping rice flood disaster

◻ Temporal distribution of early rice flood disaster

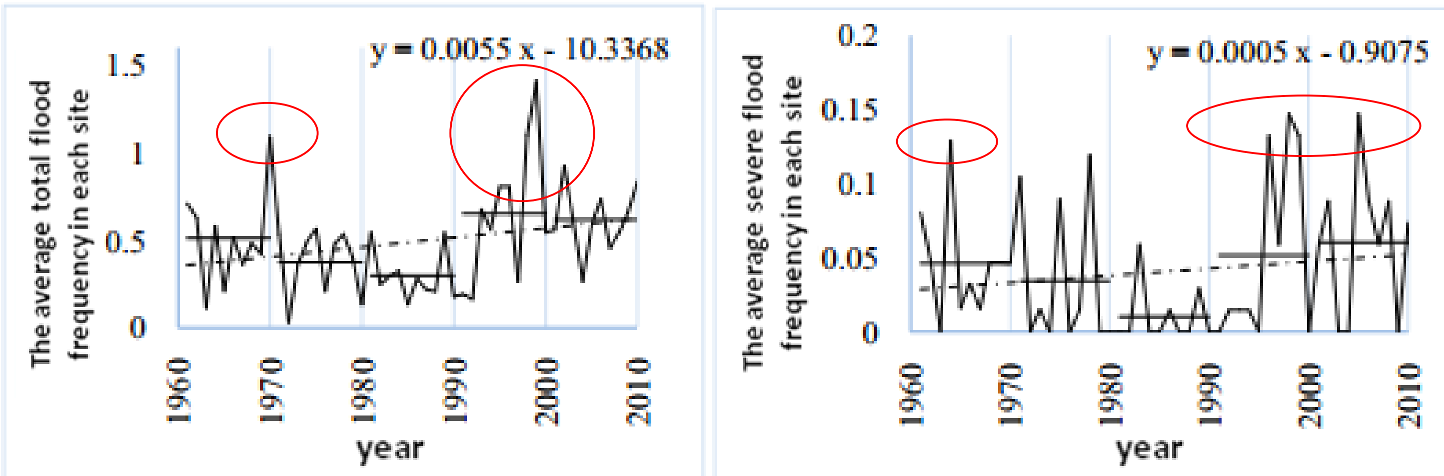


Fig. 3.1 Interannual change of early rice total flood and severe flood frequency

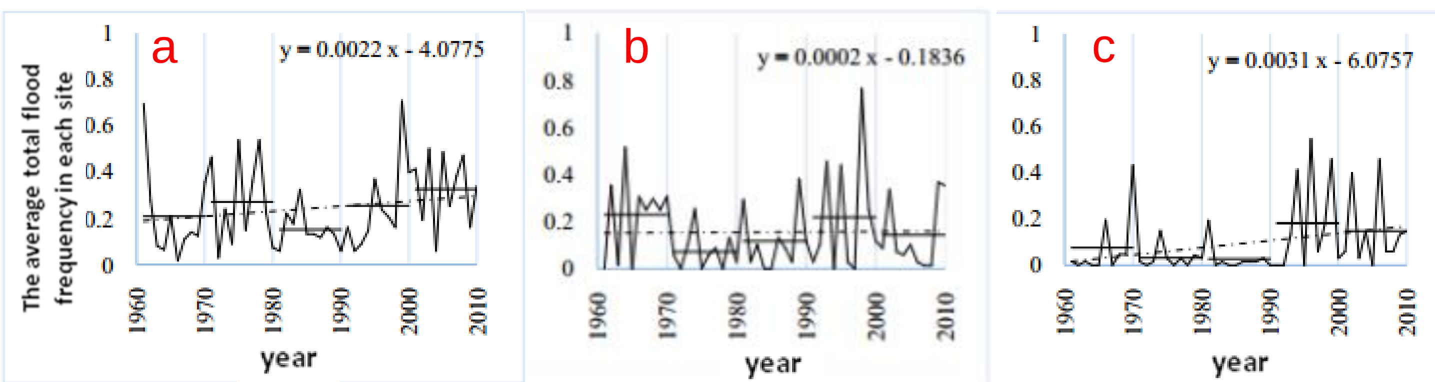


Fig. 3.2 Interannual change of early rice total flood in: a. transplanting-jointing stage; b. booting-blooming stage; c. milk-maturity stage

Temporal distribution of late rice flood disaster

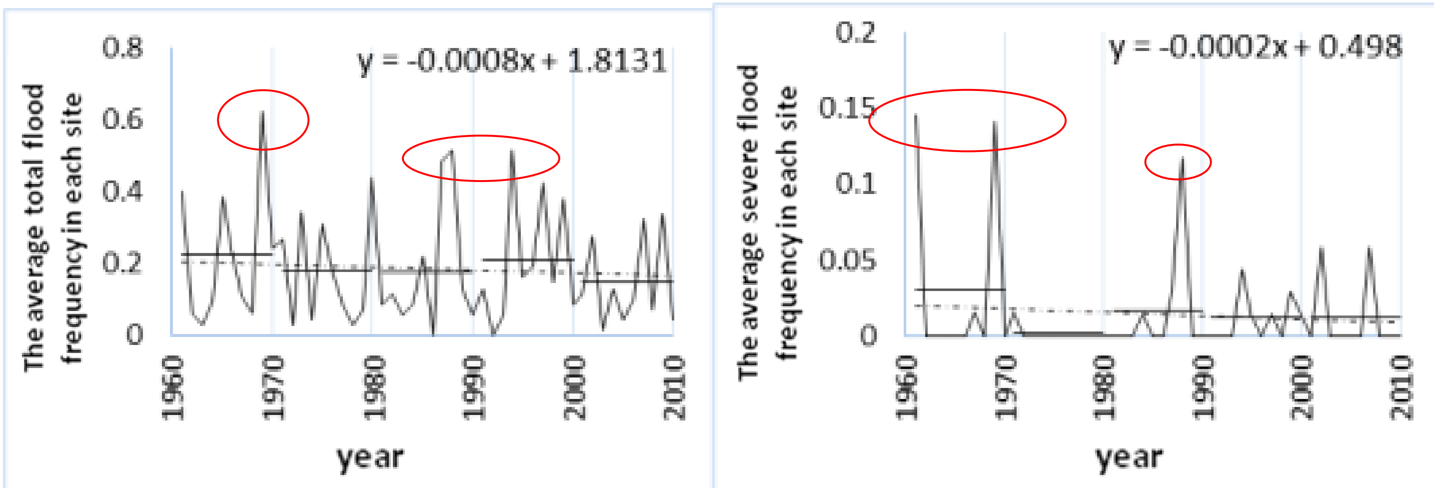


Fig. 3.3 Interannual change of late rice total flood and severe flood frequency

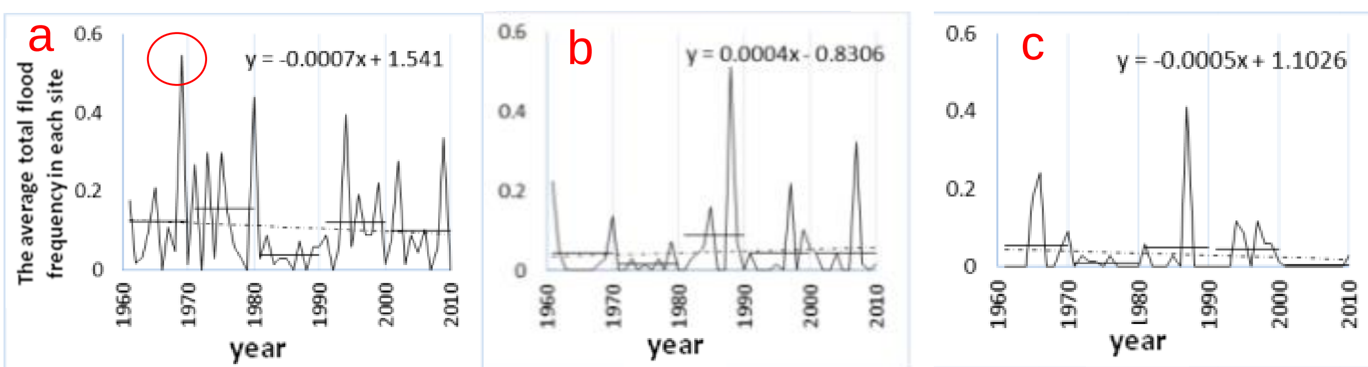


Fig. 3.4 Interannual change of late rice total flood in: a. transplanting-tillering stage; b. jointing-booting stage; c. blooming-maturity stage

◻ Spatial distribution of double-cropping rice flood disaster

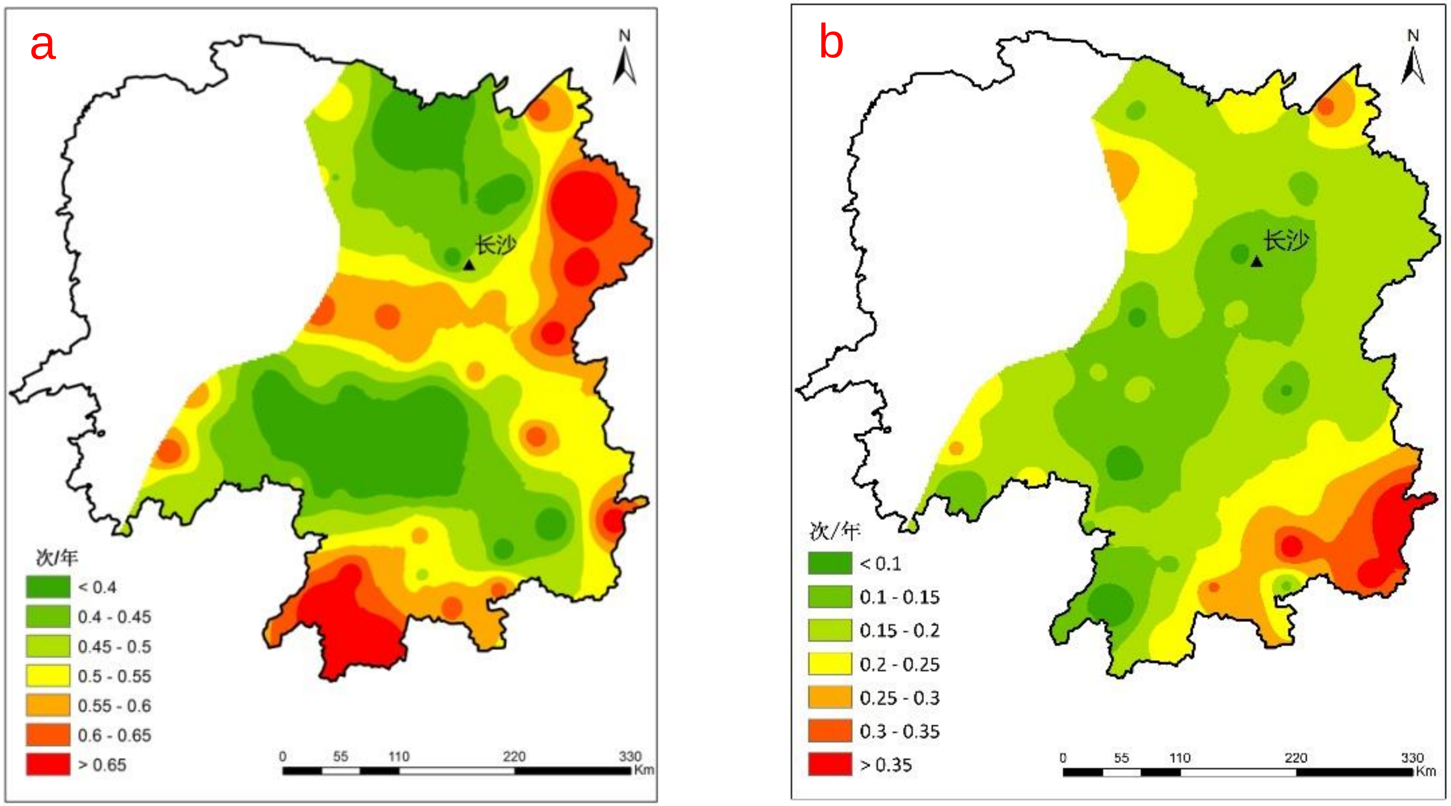


Fig. 3.5 Distribution of double-cropping rice total flood frequency in Hunan province in 1961 to 2010
(a. Early rice; b. Late rice)

Risk assessment of double-cropping rice flood disaster

Double-cropping rice flood disaster risk assessment model

- **4 factors risk assessment model:**

$$DRI = H^{w_h} \times E^{w_e} \times V^{w_v} \times R^{w_r}$$

DRI: risk index;

H: hazard;

E: exposure;

V: vulnerability;

R: Emergency response and recovery capacity;

w_h, w_e, w_v, w_r: the weight of *H, E, V, R*, respectively.

Hazard assessment model

- **Including two kinds of indexes:**

  Hazardous intensity and disaster frequency

$$H = \sum_{i=0}^{3} f_i \cdot w_i$$

H: hazard index

f_i: frequency of *i* level flood disaster;

w_i: weight of *i* level flood disaster;

i=1: light flood; *i*=2: moderate flood; *i*=3: severe flood.

- Widespread flood disaster happened in the year 1987, 1993, 1994, 1996, 1997 and 1999 in Hunan. Calculate the relative meteorological yield caused by flood disaster.

- **Relative meteorological yield:**

$$y_p = \frac{y - y_t}{y_t} \times 100\%$$

y_p: relative meteorological yield;

$-y_p$: yield reduction rate (when $y_p<0$);

y: actual yield;

y_t: trend yield.

- Construct regression equations between county double-cropping rice yield reduction rate and site light, moderate, severe flood frequency. Averaged regression coefficient as the weight of light, moderate and severe flood disaster.

Table 4.1 Weight of each flood disaster level of double-cropping rice

Flood disaster level	Light	Moderate	Severe
Weight in early rice	0.3266	0.5245	1.2977
Weight in late rice	0.3533	0.7463	1.0151

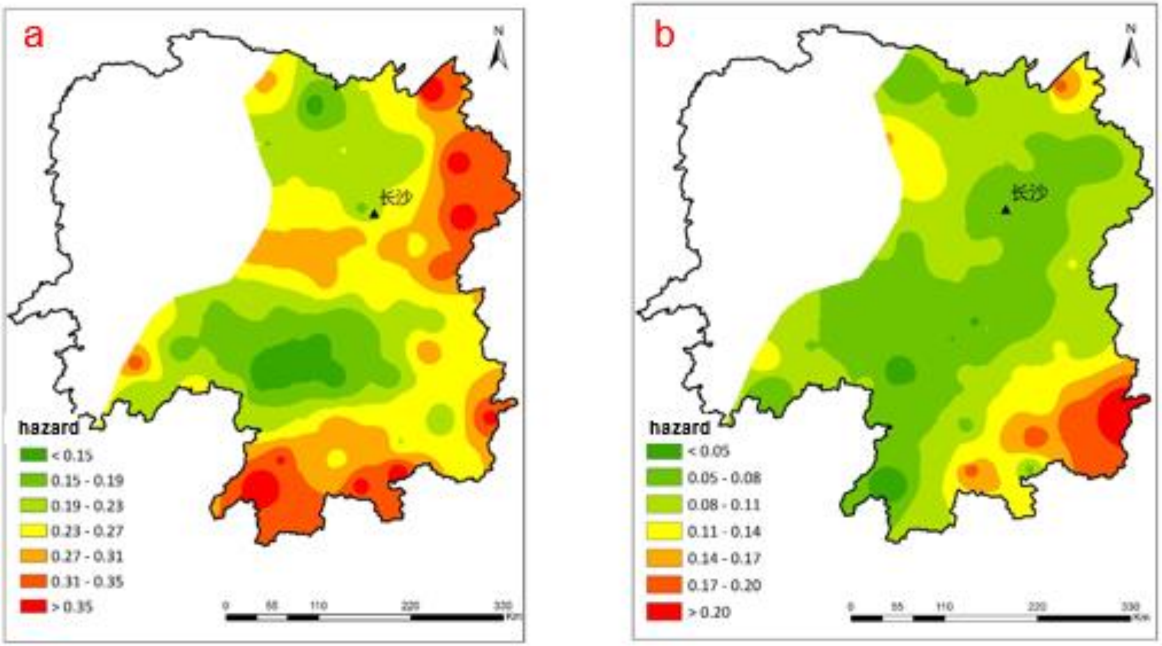


Fig. 4.1 Hazard index distribution of double-cropping rice flood disaster in Hunan (a. early rice; b. late rice)

Exposure & Vulnerability assessment model

☐ Double-cropping rice coverage

$$E = \frac{S}{S_f}$$

E: exposure index;

S: double-cropping rice cultivated area;

S_f: farmland area; data from *Statistical Yearbook of Hunan (2008)*

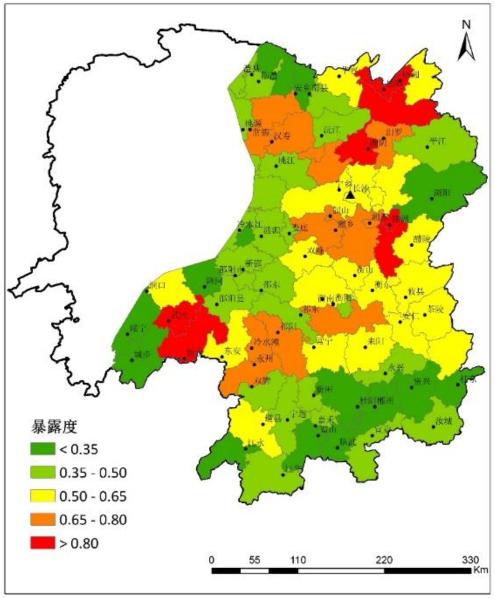


Fig. 4.2 Exposure index distribution of double-cropping rice

☐ Vulnerability under the threat of disaster

$$V = \frac{\sqrt{\frac{\Sigma_{i=1}^{n}\left(y_{q,i} - \bar{y}_q\right)^2}{n-1}}}{\bar{y}_q}$$

V: vulnerability index;

$y_{q,i}$: yield reduction rate in year i;

$\bar{y}_q$: average of yield reduction rate.

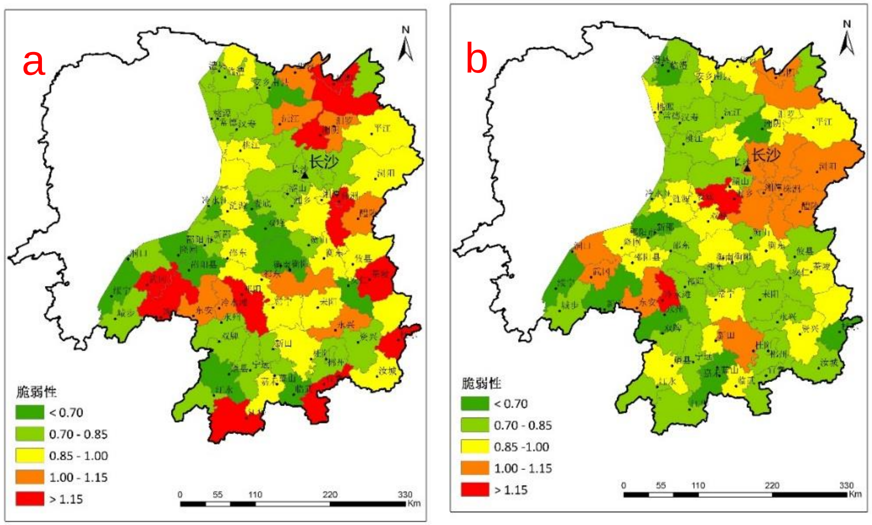


Fig. 4.3 Vulnerability index distribution of double-cropping rice (a. early rice; b. late rice)

Emergency response & recovery capacity assessment model

- **Considering the influence of human activities on the flood defense, select 3 sets of indicators for assessment.**

$$D = N^{w_n} + I^{w_i} + F^{w_f}$$

D: Emergency response and recovery capacity index;

N: net income per capita;

I: the unit area of total power of mechanical facilities of irrigation and drainage;

F: the unit area of chemical fertilizers;

w_n、w_i、w_f: the weight of *N, I, F*, respectively.

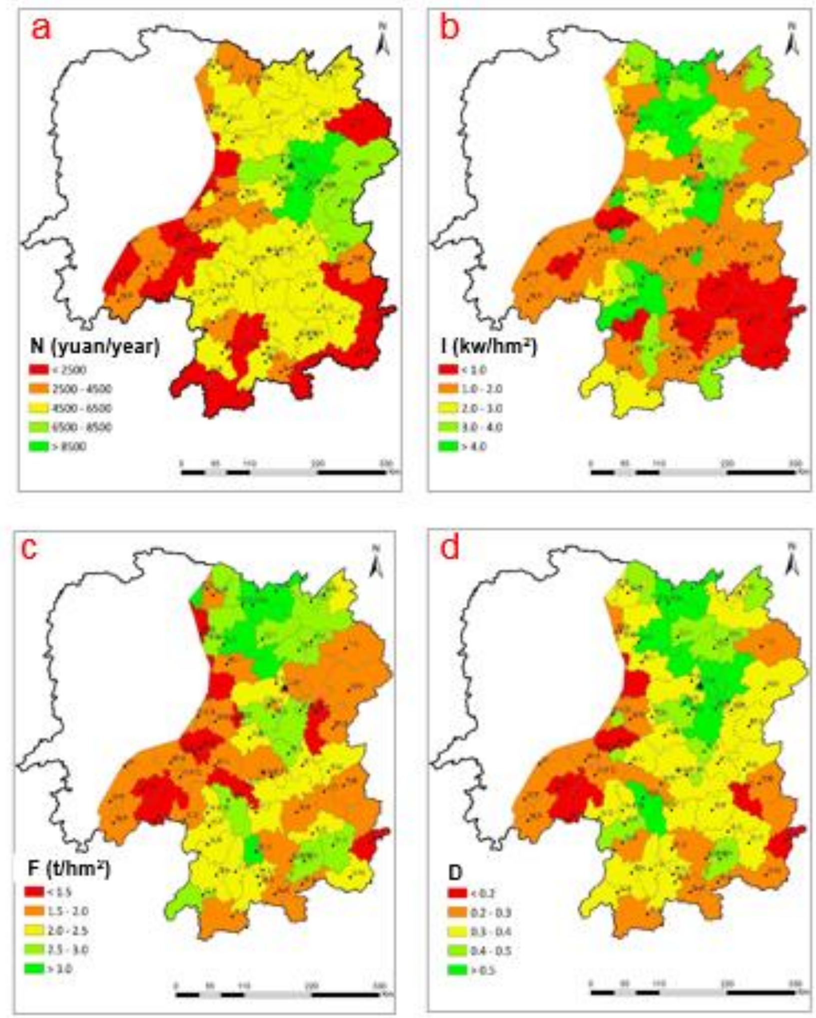


Fig. 4.4 Emergency response and recovery capacity index distribution in Hunan province (a. net income per capita; b. the unit area of total power of mechanical facilities of irrigation and drainage; c. the unit area of chemical fertilizers; d. total capacity)

Double-cropping rice flood disaster risk assessment

- Emergency response & recovery capacity factor exhibit negative contribution to flood disaster risk.

In flood disaster risk assessment model:

$$DRI = H^{w_h} \times E^{w_e} \times V^{w_v} \times R^{w_r}$$

define *R*:

$$R = \frac{1}{D}$$

Table 4.2 Weight of double-cropping rice flood risk assessment factors (using entropy method)

Assessment factor	Hazard	Exposure	Vulnerability	Emergency response & recovery capacity
Weight in early rice	0.2373	0.2515	0.2540	0.2573
Weight in late rice	0.2606	0.2401	0.2520	0.2473

◻ Verify double-cropping rice flood risk assessment model

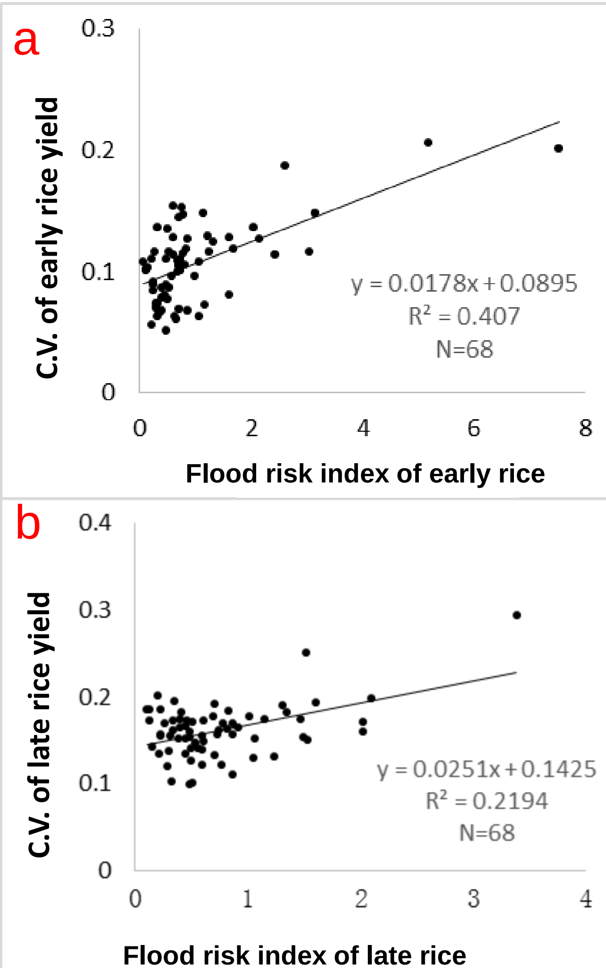


Fig. 4.5 Correlation analysis between flood risk index and C.V. of double-cropping rice yield (a. early rice; b. late rice)

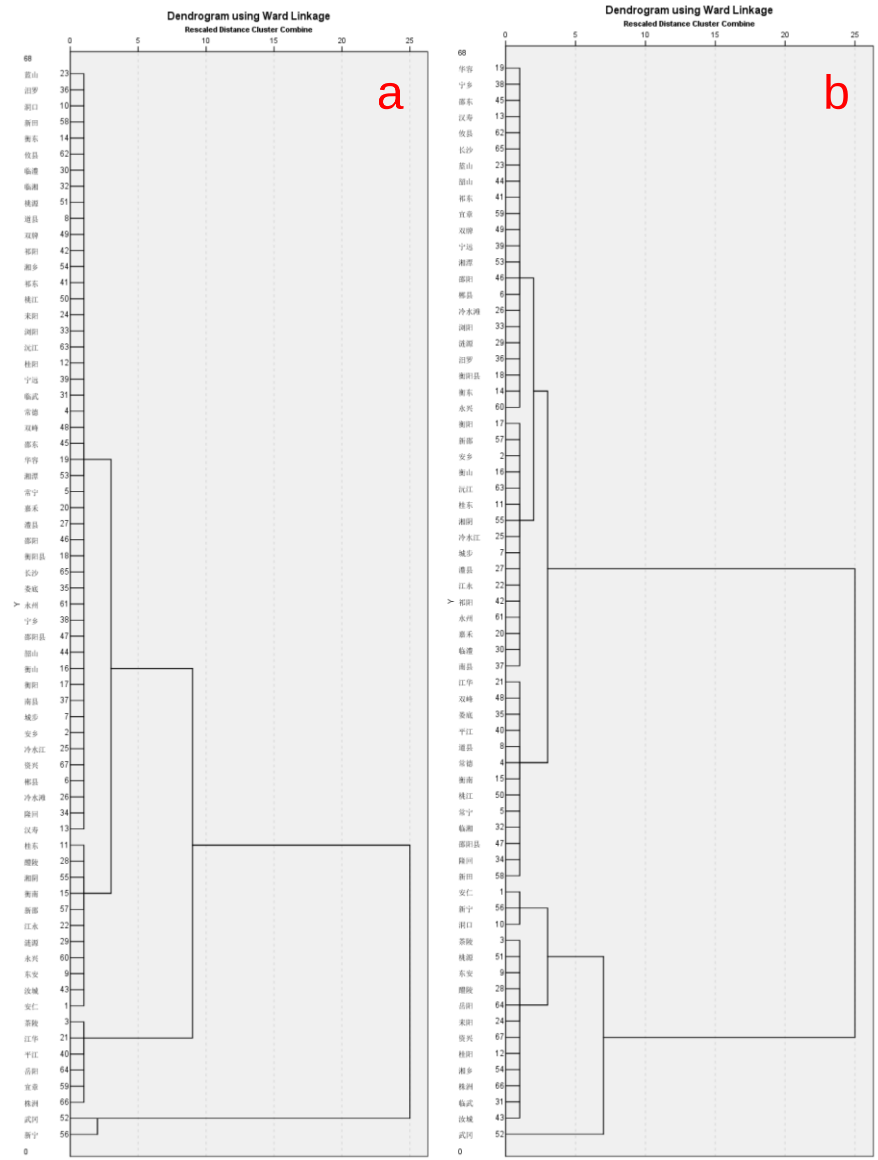


Fig. 4.6 Double-cropping rice flood risk index hierarchical cluster graph based on Ward's method (a. early rice; b. late rice)

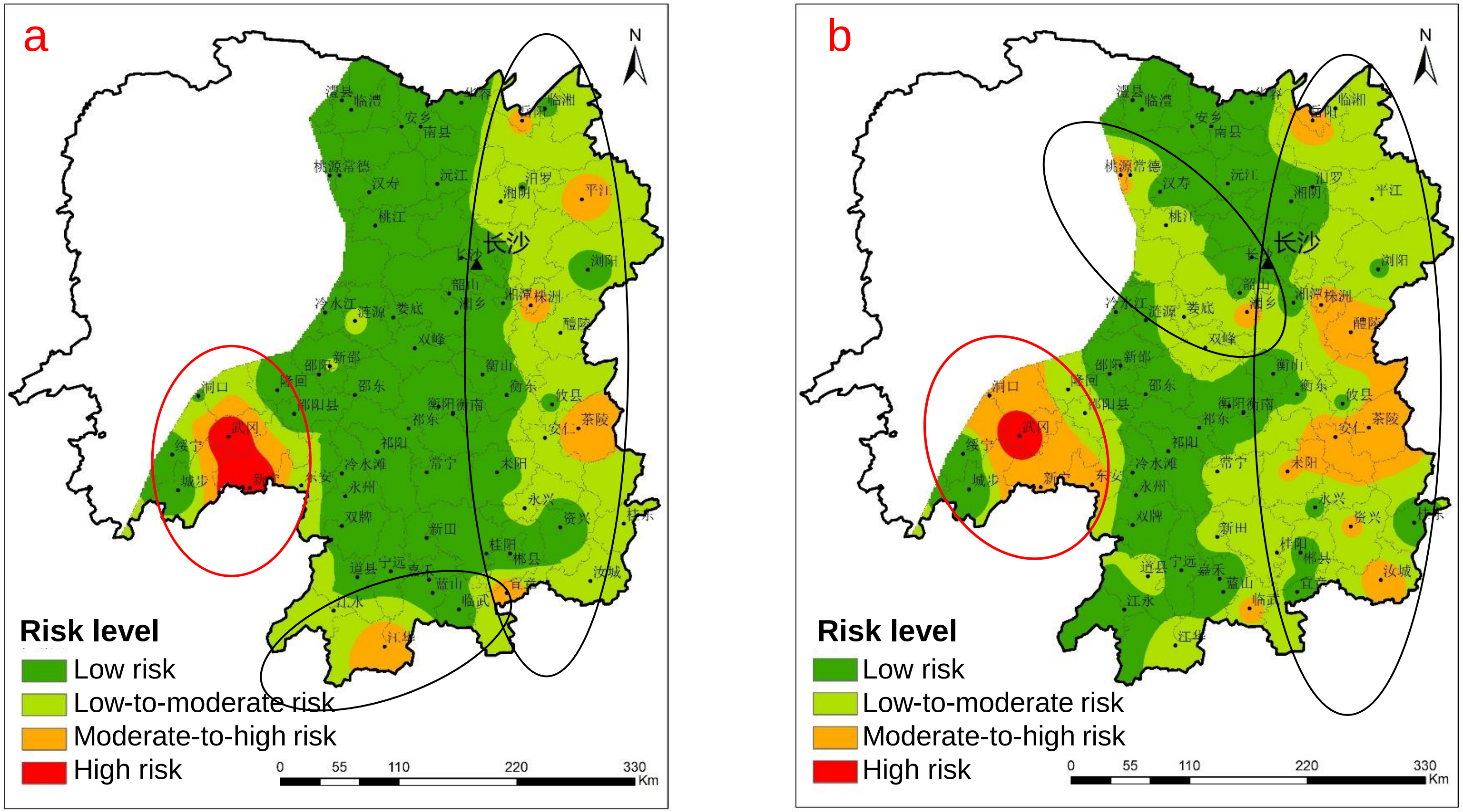


Fig. 4.7 Double-cropping rice flood disaster risk zoning (a. early rice; b. late rice)

Discussion

- Historical records such as *China Meteorological Disaster Authority* is rich in historical information, which is worth of fully tap and actual use.

- Previous studies of early rice flood is given priority to field experiment, there is no rainfall meteorological flood level index research. Booting-blooming indicators determined in this paper is higher than that of transplanting-jointing, but lower than milk-maturity, the conclusion is in conformity with field control tests' results (Li *et al*., 2004; Yin *et al*., 2009). Analysis results of early rice flood interannual and interdecadal distribution are conform to the historical records and previous flood area research, on the other hand, suggests the accuracy of constructed indicators.

- The Yangtze river basin rainstorm is with local characteristics of the continuous heavy rainfall (Bao, 2007), site precipitation data has limitation reflecting the regional rainfall.

- Used C.V. of yield reduction rate as vulnerability index in vulnerability assessment model. However, not only flood disaster , other disasters such as drought and chilling injury, also played important role in yield fluctuation.

- Emergency response and recovery capacity linked closely to local society, economy, culture and other factors. This paper selected 3 sets of indicators for assessment. It needs to take further research on background if there are other indicators make contribute to this factor.

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Thanks

Welcome to leave your valuable opinions and suggestions!