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# Yellow River Valley flood and drought disaster: spatial-temporal distribution prediction and early-warning

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**Abstract**——By means of analysing the historical data of flood-drought grade series in the past 2000 years (A.D. 0—1900), especially in the last 5000 years (1470—1900), this paper revealed the spatial-temporal distribution features of severe flood and drought in Yellow River Valley. Statistical methods of variance analysis, probability transition and the principles of scale correspondence were employed to comprehensively predicate 90's tendency of severe flood and drought in the Yellow River Valley. In addition, this paper pointed out the possible breaching dikes, sectors and the flooding ranges by future's severe flood, meanwhile estimating the associated economic losses and impact to environment.

**Keywords**: Yellow River Valley; flood and drought disaster; spatial-temporal distribution; prediction and early-warning.

## 1 Introduction

China will be entering a new developing era from now to the year 2000. By 2020, the mid-term targets of China's industrialization project will be accomplished. In the initial and mid stages of this industrialization process, economy is being developed rapidly and those industries consuming numerous resources and discharging large amounts of wastes are bringing about a series of environmental problems, for example, the urban scope and urban infrastructure can not meet the increasing demand caused by rapid population growth; the degradation of urban environmental quality caused by housing shortage, traffic jam and environmental pollution; the excessive resources exploitation and the aggravation of environmental pollution hastened by the development of rural and township industries; soil erosion, land quality degradation and desertification; drought and flood disasters; shortage of water resources decrease of biological species and so on. All these environmental problems have been turned into severe obstacles for social and economic development. The major points of ecological environment early warning research include how to deal with the relationship between resources exploitation and environmental protection, how to harmonize the economic development and environmental quality, how to crub or alleviate environmental deterioration and to reduce unnecessary losses and how to avoid decision blunders.

According to the variant research objects and tasks, ecological environment early warning research can be divided into single object, complex, monographic, and regional early warnings. The single object early warning and monographic early warning studies are aimed at a certain object or a special subject in the ecosystem, such as the supply-demand of water resource, drought and floods disasters, soil erosion, land desertification, air pollution and so on. The complex early warning concerns several relative monographs or the entire ecosystem, such as the Chinese and the global ecological environment state, while the regional early warning takes one region as its research scope. Because the research objects are intricate and very difficult to determine their comprehensive threshold values, the complex and regional early warning emphasize on forecasting the varying tendency and aggregating degree of ecosystem state, and regional ecological rates of soil erosion in Shaanxi Province is 7370 ton/km$^2$ annually while in Shanxi Province it is 4082 tons. More than 80% of sand transmitted into the Yellow River is from Shanxi, Shaanxi, Gansu, and Ningxia Provinces. In addition, these provinces are the important energy bases for the whole country. The coal mining have brought about land desertification and landscape ruin. For improvement of the environmental quality of these provinces, regional strategic planning is an urgent task.

## 2 Spatial-temporal features of severe flood and drought and disaster early warning of Yellow River Valley

### 2.1 Spatial-temporal features of severe flood and drought in the Yellow River Valley

This paper cites 《China's last 500 year flood and drought distribution atlas》, and adopts the five grades standard system to differentiate flood and drought, namely, grade Ⅰ—flood, grade Ⅱ—partial flood, great Ⅲ—normal, grade Ⅳ—partial drought and grade Ⅴ—drought. Grade Ⅰ and grade Ⅴ are employed in this paper to refer to long-lasting and heavy rainfall, or severe flood, and drought that lasts months or quarters, or extensive and severe drought respectively. The grade evaluations are conducted under such standards:

$$\text{Grade I}: \quad R_i > (\overline{R} + 1.17\sigma)$$

$$\text{Grade II}: \quad R_i \leqslant (\overline{R} - 1.17\sigma)$$

where, $R$ is the average annual precipitation from May to September; $Ri$ is the actual monthly precipitation from May to September; and $\sigma$ is the standard deviation.

Normally, most part of Yellow River Valley has a rainfall of 200—300mm, and in the lower reaches, the rainfall amount is 400mm. The severe drought in history is about the same year in which the percentage of rainfall departure of summer in the observation period is less than or equal to minus 50% and the amount of rainfall is less than 150 mm per year in most regions of the valley. The severe flood is that the percentage of rainfall departure of summer was more than or equal to 50% and the amount of rainfall is more than or equal to 500 mm per year in most regions of the valley.

The analysis of the flood-drought grade series for 2000 years especially for the last 500 years, reveals the spatial-temporal features of flood and drought in the river valley. From the angle of spatial distribution, the Yellow River Valley comprises five relatively centralized severe flood areas and three major drought areas. As to the temporal evolution, the flood and drought frequency has gone through century-size variations for many times in the past 2000 years and there emerged five relatively drought periods, namely the 5th, 7th, 11th—12th, 14th, 16th—17th century and six relatively humid periods, the 4th, 6th, 8th—11th, 13th, 15th, 18th—19th century, and has a transferring cycle for approximately 200 years.

By applying the lst 500 year's flood and drought grade series data, the emerging frequencies of the above grade I and grade V in Lanzhou (representing the upper reaches); Xi'an, Yan'an, Yulin (representing the middle reaches); Zhengzhou' Jinan (representing the lower reaches) were figured out (Table 1). Fig. 1 is the flood and drought frequency diagram of Lanzhou, Yan'an and Jinan in various periods.

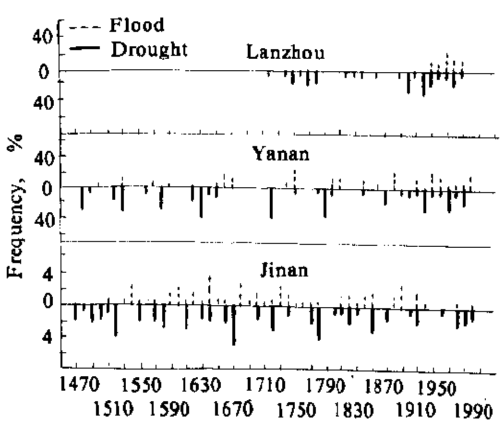


Fig. 1 Distribution of frequency of flood drought in the Yellow River Valley

Observing the evolution of the last 500 year's flood and drought, it can be found that flood frequency decreased gradually from east to west while drought frequency increases successively from the Loess Plateau towards both east and west. The greatest disparities between flood and drought frequencies exists in the upper reaches with a drought frequency four times that of flood. In the lower reaches areas, flood and drought disasters occur most frequently. Since the beginning of this century, there has been a remarkable ascendance of flood and drought frequencies in the upper and middle reaches accompanying a relative descendance of those frequencies in the lower reaches, and the decrease of flood frequency is the most evident. The frequent-occurring areas of flood and drought disasters have transferred from lower reaches by the temporal measures, and the frequencies of large range flood and drought have increased as the centuries went on, and have the highest value in the 20th century while the lowest value was in the 17th century; the flood and drought disasters in partial regions were most frequent in 17th century, and seldom in the 19th century; the lasting flood and drought have decreased with the lapse of time and were most severe during the 16th—18th century. The successive flood and drought have decreased remarkably since the 19th century.

**Table 1 Frequency of flood drought**

(Unit: %)

| Station | 520 years | | 100 years | |
|---|---|---|---|---|
| | Drought | Flood | Drought | Flood |
| Lanzhou* | 13 | 3 | 17 | 7 |
| Xi'an | 9 | 10 | 9 | 8 |
| Yan'an | 9 | 5 | 14 | 11 |
| Yulin | 10 | 6 | 12 | 10 |
| Zhengzhou | 10 | 10 | 14 | 8 |
| Jinan | 19 | 12 | 10 | 6 |

* There are 225 years of successive data in Lanzhou Station

2.2 Trend prediction of severe flood and drought in the 1990's

In this paper, the tendency of severe flood and drought in the Yellow River Valley in the 1990's is predicted comprehensively by the analysis of variance and transition probability and the principles of scale correspondence.

2.2.1 Analysis of variance

Besides the consideration of some related physical factors, the prediction of one of the meteorological factors is always based on the periodic variation law that described the change of meteorological factors with time. And then the periods with physical meanings are selected to make extrapolation for prediction. In this paper, the period is confirmed by the analysis of variance which characterizes that the period is not necessarily to be a sinusoidal wave.

In this method, the time series are divided into several groups and then the valiance of each group is analyzed and compared to confirm the possible period (Table 2).

2.2.2 Transition probability

The factor variation of variance analysis must follow stable chart, but actually, climate change is usually quasi-periodic.. Therefore, it always results in a good fitting and poor forecasting effectiveness. However, transition probability could avoid the effect of period-length to a certain degree. Differing from continuous sequence, the data of discrete distribution could be analyzed by transition probability with its evolving characteristics. Moreover, forecasting for each year is independent of one another and this method may be more suitable for discrete flood drought grade series.

**Table 2 Analysis of variance: prediction of flood drought grade in 1990's**

| Station | Year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
| Jinan | 3.6 | 4.4 | 1.9 | 3.6 | 1.9 | 3.2 | 2.5 | 2.8 | 3.9 | 2.7 | 3.6 |
| Zhengzhou | 3.8 | 4.5 | 5.0 | 2.7 | 4.2 | 2.4 | 2.2 | 2.8 | 3.5 | 2.3 | 3.8 |
| Yan'an | 3.9 | 5.0 | 2.4 | 4.2 | 2.7 | 1.7 | 4.0 | 2.7 | 2.8 | 2.0 | 4.1 |
| Xi'an | 2.5 | 2.0 | 5.0 | 1.6 | 4.3 | 1.8 | 3.2 | 3.7 | 2.8 | 2.3 | 3.1 |
| Lanzhou | 2.5 | 0.8 | 5.0 | 4.4 | 2.6 | 4.5 | 3.1 | 1.8 | 3.9 | 4.3 | 2.6 |
| Xining | 5.0 | 2.8 | 2.8 | 4.2 | 2.1 | 2.9 | 3.1 | 2.8 | 2.8 | 4.2 | 2.6 |

The main method of transition probability is to predict the appearing probability of flood or drought on the basis of the appearing probabilities of every flood drought grade in one, two, three, and even then years after a certain grade flood or drought. By experience, one hundred year's data are usually adequate for ten-year prediction. Table 3 is the forecasting result of the 1990's flood drought grade by using five-step **transmissibility method in six stations.**

**Table 3 Transition probability: prediction of flood drought grade in 90's**

| Station | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 |
| Jinan | 4 | 2 | 3 | 2 | 3 | 1 | 3 | 4 | 3 | 2 |
| Zhengzhou | 4 | 3 | 2 | 4 | 3 | 3 | 3 | 4 | 2 | 4 |
| Yan'an | 3 | 1 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 1 |
| Xi'an | 2 | 2 | 3 | 3 | 3 | 4 | 3 | 2 | 4 | 4 |
| Lanzhou | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Xining | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 2 |

2.2.3 Scale correspondence method

In this paper, relationship between astronomical background and climate change is studied by the stability and predictability of the astronomical factors according to the scale correspondence method. At present, the most popular method applied is to predict the climate tendency according to statistical relationship between the sunspot number and climate change.

Comparing the evolving curve of sunspot number among the numbers of severe flood and drought occurred in the Yellow River Valley from the year 1700 to 1900, it is founded that severe flood occurred mostly in sunspot peak year and severe drought in low years (Fig. 2).

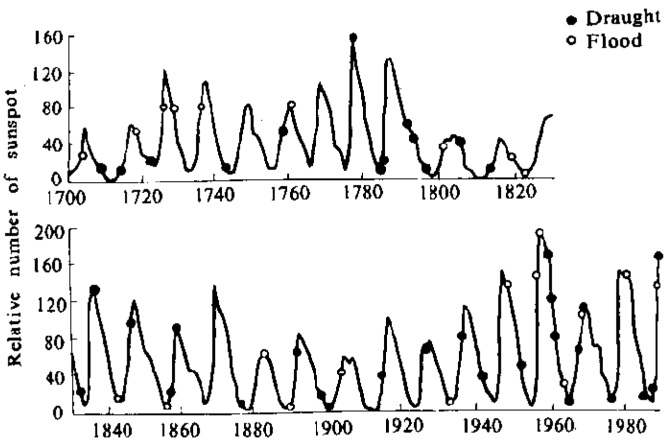


Fig. 2 Relationship between number of sunspot and flood drought in the Yellow River Valley

2.2.4 Trend prediction of severe flood drought in the 90s

From the above analysis, it can be predicted that rainfall in coming ten years will have a great increase than that in the 80s in the Yellow River Valley and it will get into a humid stage of the relatively dry period. This rainfall condition will keep on for more than ten years because of the slight climate change. There is little probability of long-lasting and large-scope flood or drought occurring between the year 1991 and 2000, but flood drought of different grade may take place in some local regions during that time. It is predicted that, in early 1990′s, there may be severe flood drought and severe drought occurring, respectively, in the upper and the middle reaches, Meanwhile, there may be a severe flood in early 1990′s and late 1990′s respectively; a severe drought in early 1990′s in the lower reaches; and a severe flood in middle 1990′s.

## 3 Prediction and warning of the Yellow River flood

3.1 Characteristics of the river channel in the lower reaches of the Yellow River

The river channel of the lower reaches is in its old-age with following characteristics: (1) It becomes an aboveground river because of sedimentation of the riverbed. For example, the river reach of Huayuankou is about five meters higher than the ground level of northern suburb of Zhengzhou City, and 11.5 meters higher than that of Xinxiang

City and there is a height difference of 6—7 meters between the face and back of the dike. (2) More and more erosion of the dike increases the width of riverbed. Before the dike was made the river oscillated to form braid-like waters between the alluvial fan and the delta. After that, the riverbed is still widening between the dikes. (3) The slope of riverbed is reducing because of the erosion of the river mouth. (4) The base level erosion has more and more effects on the variation of the lower reaches. (5) There is a lifting trend of the vertical section of accumulated river. The lower reaches have become accumulated quasi-plain rivers and the vertical section is almost parallel lifting. At present, the key flood control project is in the Huayuankou Station. When the maximum water discharge is beyond 22000 $m^3/s$, it will make flood diversion to the flood retarding basin. In history, the maximum water discharge was 32000 $m^3/s$ at Huayuankou Station. The analysis of flood data in the river basins of Haihe River and Huaihe River indicates that it is possible to have severe flood with a water discharge of 49000—55000 $m^3/s$ in the lower reaches that will exceed greatly the flood control capacity of all the projects existing now. Even though the Xiaolangdi Reservoir has been build up, there still is a possibility to have severe flood because of the clogging by soil and sand after 30 to 50 years.

3.2 Possible breaching dikes

By the analysis of historical data of dike breaching and the evolving process of the lower reaches during the last 5000 years, the period of the river channel in the north region was the longest and lasted about 3320 years; that in the middle about 146 years; and in the south about 661 years. Since the year of 1855, the river channel had come back to the middle region, i. e., the existing channel currently for about 120 years. In future, the river channel may trend towards north according to its evolving regulation in history and the characteristics of river channel existing now.

At present, there is a great height difference between the face and back of the dike with the higher south and the lower north. In the direction of dike, the height of the back of the southern dike is 2—5 meters higher than that of the north in the reach from Hank to Jiahetan; and in the vertical direction of dike, the southern dike is about 2 meters higher than the north in the equal distance from the dike. Therefore, the northern dike has more possibility to breach. The distribution of dike breaching to north in the lower reaches between the year 1855 to 1934 is described in Table 4 where the density of dike breaching means the dike breaching numbers per kilometer per ten years. As indicated in Table 4, the maximum density of dike breaching is in the reach from Dongbatou to Sunkou (between the year 1925 and 1934) which was situated in front of alluvial fan.

**Table 4 Dike breaching density of the north bank in the lower reaches of Yellow River (1855—1934)**

| Year | Yiluohekou-Dongbatou, 165. 9km | | Dongbatou-Sunkou, 190. 5km | | Sunkou-Luokou, 161. 7km | | Luokou-Lijin, 16. 7km | |
|---|---|---|---|---|---|---|---|---|
| | Frequency | Density | Frequency | Density | Frequency | Density | Frequency | Density |
| 1855—1864 | | | 1 | 0. 05 | | | 2 | 0. 12 |
| 1865—1874 | | | 2 | 0. 11 | | | 3 | 0. 18 |
| 1875—1884 | | | 1 | 0. 05 | 2 | 0. 12 | 14 | 0. 83 |
| 1885—1894 | | | 6 | 0. 32 | 4 | 0. 25 | 14 | 0. 83 |
| 1895—1904 | | | 5 | 0. 25 | 2 | 0. 12 | 9 | 0. 54 |
| 1905—1914 | | | 6 | | | | | |
| 1905—1924 | | | 3 | 0. 16 | | | | |
| 1925—1934 | 2 | 0. 12 | 35 | 1. 84 | | | | |

3. 3 Computation of inundated area

Considering the above-mentioned analysis as well as density of dike breaching in different river reach in history and the capacity of flood control project, the reaches from Qinhekou to Yuanyang and Yuanyang to Gaocun especially the reach from Qinhetan to Gaocun, may be the most dangerous in all the reaches. Therefore, the computing of dike breaching for the northern bank is based on the simulation of these two reaches. Moreover, there are also great meaning in economic analysis for the largest inundated areas and greatest losses in economics.

3. 3. 1 Calculating method

Flood survey method was adopted in the past to confirm inundated area in the lower reaches. Now, the mathematical models are made by hydraulics methods to define inundated areas. The condition of dike breaching is very similar with dike burst due to the great height difference between the face and back of dike in the lower reaches. Therefore, considering the effects of water discharge and topography, the calculating result by the method based on the law of dike burst fits very well.

The flood in dike breaching is an unstable flow which changes with time. This kind of unstable flow is usually described as follows:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0$$

$$\frac{\partial Z}{\partial x} + \frac{V}{g} \cdot \frac{\partial V}{\partial x} + \frac{1}{g} \cdot \frac{\partial V}{\partial t} = - S_f,$$

where, $A=A(t,h)$ is cross-sectional area; $Q=Q(x,t)$ is water discharge; $Z=Z(x,t)$ is river stage; $V$ is average flow velocity on cross section; $t$ is time; $X$ is abscissa in the direction of flow; $h=Z(x,t)-Z_0(X)$ is water depth; $Z_0(X)=Z(x,t)I_{h=0}$ is altitude of river bottom; $S_f=n^2Q^2/A^2h^{2/3}$ is drag factor and n is Manning roughness coefficient.

Near the entrance to sea, the flood flow becomes diffusively connected flow whose velocity is between that of homogeneous and critical flow is described as follows:

$$h_t = \frac{1}{2}\left[\frac{Q^{2/3}}{B^{2/3}\cdot g^{1/3}} + \left(\frac{nQ}{BJ^{1/2}}\right)^{2/5}\right],$$

where, $Q$ is water discharge, $m^3/s$; $B$ is the width of the mouth of dike, m; $n$ is Manning roughness coefficient; $J$ is the shoal slope outside the mouth of dike; and $g$ is acceleration of gravity, $m/s^2$.

Then maximum inundated area is calculated according to the value of $Q$-$Z$ and the maximum width of the cross section.

3.3.2 Inundated area

The inundated areas are influenced by the topography and the control dikes and the flood with different frequency. The simulation result of the inundated areas of dike breaching in Yuanyang and Caogang in the north bank is that the south boundary Jinan is the dike of the Yellow River and the downward Jinan is near the north dike of Tuhaihe River; the north boundary upward Nanle is the highland of palaeoriverbed and that downward Nanle is the south dike of Majiahe River. It is clear that the north boundary is within the Majiahe River and the area is about 14.9—22.1 thousand square kilometers.

The relationship between inundated area and water discharge of flood peak is that: dike breaching in Yuanyang; dike breaching in Caogang. The inundated area of above two breaching are described as Table 5.

**Table 5 Inundated areas of dike breaching in Yuanyang and Caogang**

| Dike breaching reach | Water discharge in flood peak, $m^3/s$ | Inundated areas, $km^2$ |
|---|---|---|
| Jinhekou-Yuanyang | 55300 | 22082 |
| | 49000 | 20928 |
| | 22300 | 15316 |
| Yuanyang-Gaocun | 55300 | 21190 |
| | 49000 | 20172 |
| | 22300 | 14916 |

## 4 The loss of flood disaster and its effects on environment

It is estimated that the maximum inundated areas are 22 thousands square kilometers with 12 million people, 32 counties and 29 towns if the dike breaching occurs in the north bank. Moreover, the losses of croplands, railway, oil field, and disaster city are estimated to be 22 billion RMB Yuan (Table 6). The flood disaster will make a great influences on the topography, waters, soil and hydrographic geology and make the flood inundated area poor and backward for a long time.

**Table 6 Estimated losses of disaster area**

| Dike breaching reach | Water discharge in flood peak, $m^3/s$ | Inundated areas, $km^2$ | Population in disaster areas, $10^4$ | Comprehensive losses, 100M Yuan | Crop land, 100M Yuan | Railway, 100M Yuan | Oil field, 100M Yuan | Disaster city, 100M Yuan | Total, 100M Yuan |
|---|---|---|---|---|---|---|---|---|---|
| Yuanyang- | 55000 | 22082 | 1190 | 156.62 | 1.0 | 41.7 | 0.1 | 22.4 | 221.82 |
| Fangcun | 4900 | 20928 | 1130 | 145.37 | 1.0 | 33.6 | 0.1 | 18.0 | 198.07 |
| | 22300 | 15316 | 827 | 104.55 | 1.0 | 8.7 | 0.1 | | 114.35 |
| Jinhekou- | 55000 | 21190 | 1140 | 150.22 | 1.0 | 14.1 | 0.1 | | 165.42 |
| Yuanyang | 49000 | 20172 | 1090 | 139.95 | 1.0 | 11.28 | 0.1 | | 152.33 |
| | 22300 | 14916 | 805 | 101.45 | 1.0 | 8.46 | 0.1 | | 111.01 |

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