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Feature analysis and prediction of ice regime in the source region of the Yellow River

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Abstract The Yellow River is a river where serious ice disasters frequently take place in winter. In recent years, the stable frozen period has decreased and the frequency of intermittent freeze periods has increased. After analysing the main factors influencing the ice regime, the prediction factors can be selected. Using multiple linear regression (MLR) and artificial neural network (ANN) methods, this paper sets up two models for the freeze-up and break-up date prediction. In the MLR model, stepwise regression analysis is used to select the highly-related factors into the prediction equation. In the ANN model, a multilayer preceptor in SPSS, a statistical analysis software named Statistical Product and Service Solutions, is used to set up topology between input factors and output date. In conclusion, a comparison is made between the results of the two different methods. The ANN model performs better than the MLR model.

Key words Yellow River; ice regime; ice forecasting; MLR; ANN

INTRODUCTION

Over recent years, research on the importance of river ice regime has been recognized in China and abroad. Past studies, focused on the Yellow River, presented two experimental-based mathematical models to forecast the ice conditions. One was for downstream (Chen *et al.*, 1994), and the other was for upstream (Ke *et al.*, 1998). Since the Yellow River bed changes frequently and river topographic data are lacking, the traditional mathematical model is not applicable to the ice regime forecast and more effective methods are necessary. In this paper, a multiple linear regression model and an artificial neural network system have been developed, based on the analysis of characteristics of ice regime in the source region of Yellow River.

The source region of Yellow River refers to the catchment area above Tangnaig hydrological station. Its total basin area is 121 972 km^2. The shape of the river in the source region appears like a slanting V. The length of the main stream is 270 km and the average gradient is 1.2‰. Above the Maqu station, the river flows through the plain and the slope is flat. Then it goes into the mountains and the slope become steep. The typical climate in this region is cold and dry with mean annual precipitation of 560 mm, and mean annual temperature of –4°C. Figure 1 shows the

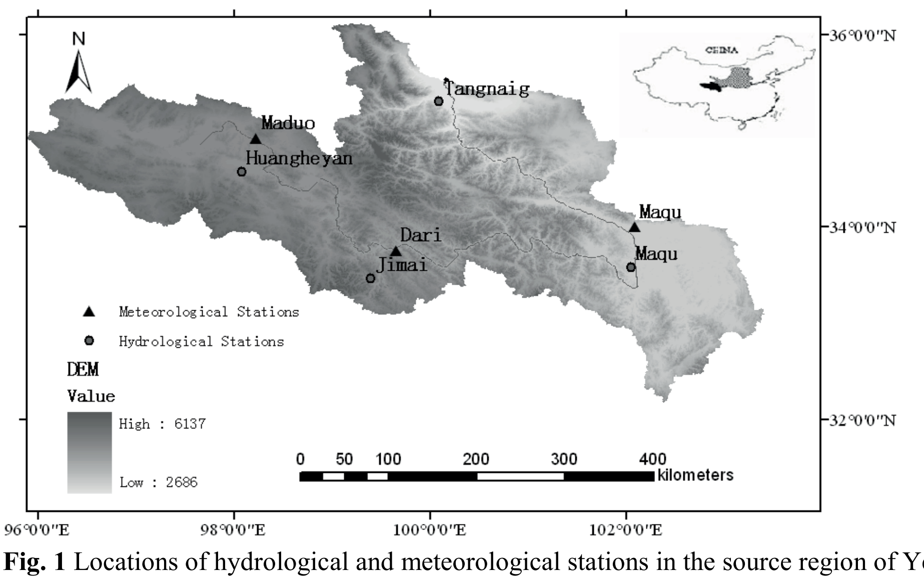

Fig. 1 Locations of hydrological and meteorological stations in the source region of Yellow River.

main river system and the gauging stations over the source region of the Yellow River. The hydrological stations used for this study include Huangheyan, Jimai and Maqu, with the corresponding meteorological stations of Maduo, Dari and Maqu.

DATA

The data analysed in this study include two parts: the meteorological data and the hydrological data for the source region of Yellow River. The former is available for the period of 1960–2010 and the latter only for 1958–1987. The data itself are not continuous, which means there are many missing points. Although the data are not completed, the study of the source region of Yellow River has always been important, as it is sensitive to climate change. The meteorological data refer to the daily average air temperature and the hydrological data refer to daily discharge, the freeze-up and break-up dates, and the maximum ice thickness.

We analyse the air temperature data compiled by the China Meteorological Administration. The dataset contains daily mean temperatures of Chinese meteorological stations. The hydrological data were obtained from the daily observations at the hydrological stations. The number of observations was increased during the freeze-up and break-up seasons. The dataset was prepared and archived by the Hydrology Bureau of the Yellow River Conservancy Committee, Ministry of Water Resources of China, in accordance with the standards of the People's Republic of China for hydrological observations.

The freeze-up and break-up dates are defined as the starting date of river freezing and the first date of ice cover movement, respectively. Accordingly, the ice cover duration is measured by the number of days between the freeze-up and break-up dates.

FEATURE ANALYSES

Features of ice regime

We made analyses of all the data we defined and derived the statistics as follows: the mean freeze-up dates for Huangheyan, Jimai and Maqu are 11 Nov., 21 Dec., and 7 Dec.; the mean break-up dates are 1 Apr., 6 Mar. and 14 Mar.; the mean maximum ice thickness are 0.95 m, 0.58 m, and 0.42 m. Figure 2 shows the freeze-up and break-up dates, frozen duration and maximum ice

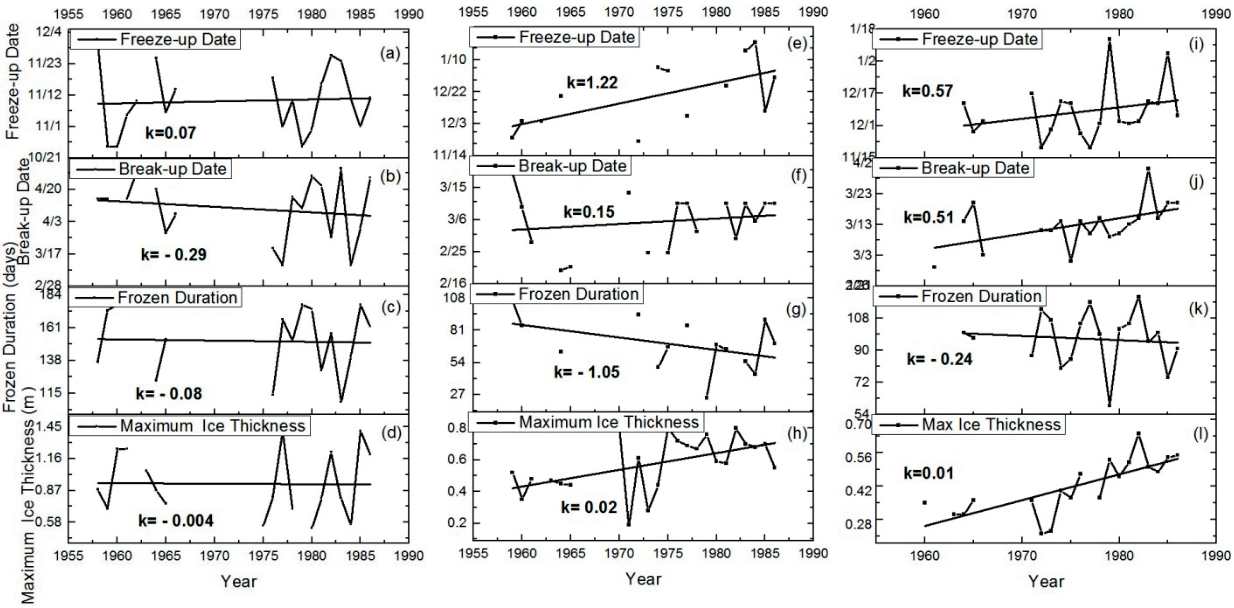

Fig. 2 Records and trend of freeze-up date, break-up date, frozen duration and maximum ice thickness of three stations: (a), (b), (c) and (d) are data from Huangheyan Station; (e), (f), (g) and (h) are data from Jimai Station; (i), (j), (k) and (j) are data from Maqu Station.

thickness of Huangheyan, Jimai and Maqu Station for the whole research period. Figure 2 shows the time series and trend lines, and several conclusions can be made: the freeze-up dates of the three stations all show the trend of delay, the break-up dates show different trends but the frozen duration still all show the trend of decrease. The maximum ice thickness of Huangheyan is reducing and the records of Jimai and Maqu both show an upward trend.

The influence factors

Channel conditions As the channel conditions are stable for decades, they can be counted as constants.

Thermal factors There are many important thermal factors, such as air temperature, water temperature, and the most representative one – accumulated negative air temperature (T_{ane}), which can show the extent and duration of cold weather. The accumulated negative air temperature is the summation of daily temperature below 0°C in winter and those days should be uninterrupted. All continuous negative temperature days between 1 November and 31 March should be taken into the calculation.

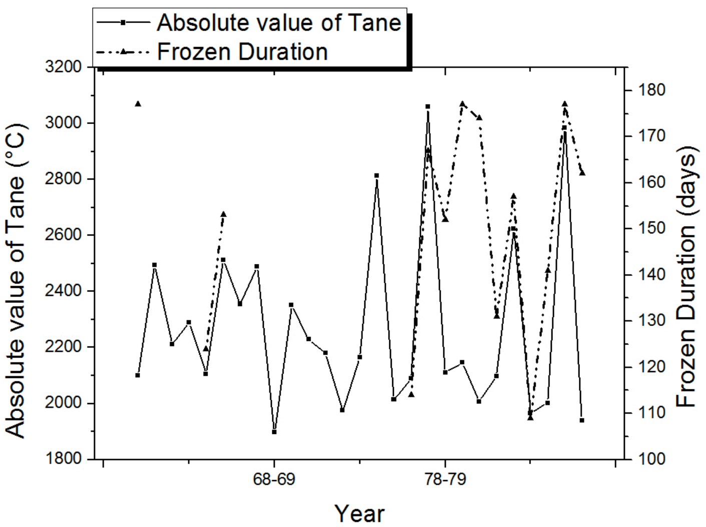

Fig. 3 The records and trend of $|T_{ane}|$ and frozen duration of Huangheyan.

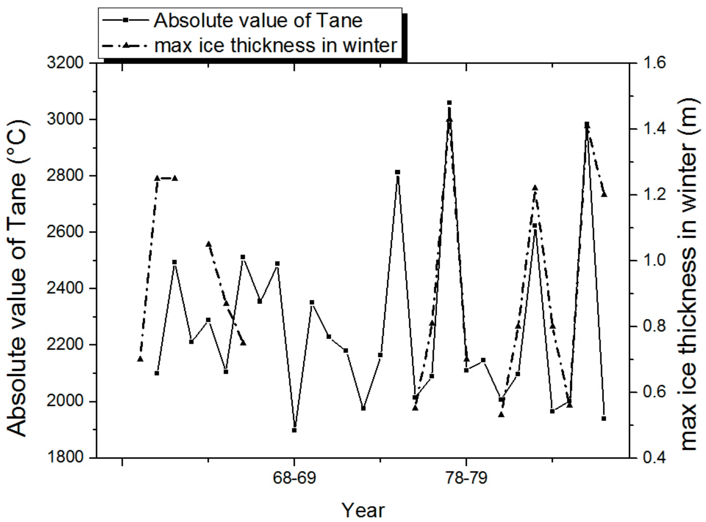

Fig. 4 The records and trend of $|T_{ane}|$ and maximum ice thickness in winter of Huangheyan.

We calculated the T_{ane} for the three stations and carried out trend analyses. We only show the Huangheyan data due to space limitations. The results show that the accumulated negative air temperature has a correlation with both the length of frozen duration and the maximum ice thickness and the three stations have the same conclusions. As the absolute value of T_{ane} increases, which means the colder the weather is, the frozen duration increases (Fig. 3). There is also a concurrent trend between the absolute value of accumulated negative temperature and the frozen duration (Fig. 4). Figures 3 and 4 show that the accumulated negative temperature can represent the severity of cold weather and it shows a good correlation with the ice regime.

Hydraulic factors

The hydraulic factors basically refer to the channel water storage and the volumetric discharge. Among these, the discharge is easy to access. Higher discharge can postpone the date of freeze-up and bring the break-up date early, even can make the river ice-free. For example, Tangnaig station is ice-free for an average year, with annual mean temperature of 1.4°C, which is colder than Maqu (annual mean temperature 1.6°C). Meanwhile, the annual mean discharge of Tangaig is 550 m^3/s which is higher than that of Maqu (455 m^3/s). Analysing the trend, there is a negative correlation between the discharge and frozen duration (also take Huangheyan as an example, Fig. 5).

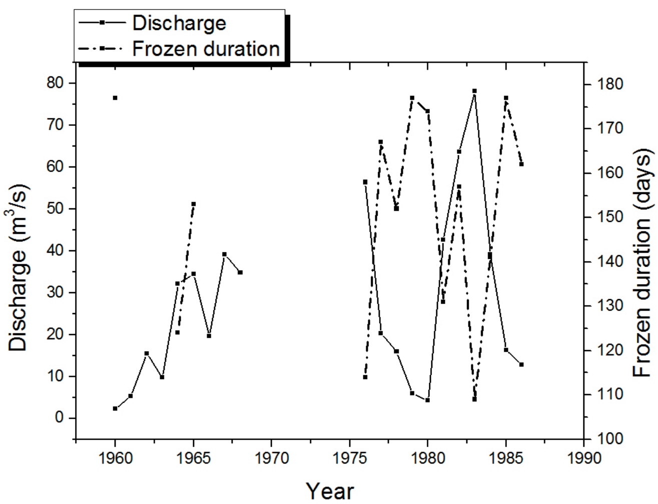

Fig. 5 The records and trend of annual mean discharge and frozen duration of Huangheyan.

FORECASTING MODEL

Analysis of the historical data indicates that many factors should be considered for attaining an accurate forecast on freeze-up date and break-up date. Not only the preceding air temperature, water level and volumetric discharge at a location of interest, but also those at the upstream areas can have significant effects on the ice conditions. In addition, the date when the air temperature goes below zero degrees is a key factor to the freeze-up date forecast. Therefore, the models for freeze-up date and break-up date forecast may be written as follows:

Multiple linear regression model

The analysis only includes the years when the river is frozen and leaves out the years when there is no ice in the river. After selecting the most related factors, the stepwise regression can be obtained. The MLR equations are listed below in Tables 1 and 2.

Table 1 The MLR equation for freeze-up date.

Station	MLR equation for freeze-up date	State
Huangheyan	$D_{ifu} = 0.387Q + 0.502D_{ne} + 24.646$ D_{ifu}: the freeze-up date for Huangheyan station Q: average discharge of late October(from 21 Oct to 31 Oct) D_{ne}: the date when temperature goes below 0°C	r: 0.998 r^2: 0.993 σ: 65%
Jimai	$D_{ifu} = 2.657D_{ne} + 21.202$ D_{ifu}: the freeze-up date for Jimai station D_{ne}: the date when temperature goes below 0°C	r: 0.718 r^2: 0.454 σ: 53.3%
Maqu	$D_{ifu} = -0.839D_{ne} + 0.916T_{ane} - 2.898D_{ne8} - 7.232T_w + 0.059Q - 28.676T_{aw} + 557.47$ D_{ifu}: the freeze-up date for Maqu station D_{ne}: the date when temperature goes below 0°C T_{ane}: the accumulated negative temperature of 30 days after D_{ne} D_{ne8}:the date when temperature goes below –8°C T_w: the water temperature of D_{ne} Q: average discharge of November T_{aw}: the average water temperature of D_{ne} D_{ifu}, D_{ne}, and D_{ne8} stand for the numerical order as 1 Oct. is 1.	r: 0.878 r^2: 0.698 σ: 83.2%

Table 2 The MLR equation for break-up date.

Station	MLR equation for break-up date	State
Huangheyan	$D_{ibu} = 1.528\ D_{pl5} - 2.116$ D_{ibu}: the break-up date for Huangheyan D_{pl5}: the date when air temperature goes above –5°C D_{ibu} and D_{pl5} stand for the numerical order as 1 Mar. is 1.	r: 0.807 r^2: 0.627 σ: 63%
Jimai	$D_{ibu} = 0.597\ D_{pl7} + 22.170$ D_{ibu}: the break-up date for Jimai D_{pl7}: the date when air temperature goes above –7°C D_{ibu} and D_{pl7} stand for the numerical order as 1 Feb. is 1.	r: 0.623 r^2: 0.356 σ: 62.5%
Maqu	$D_{ibu} = 0.463\ D_{pl} + 24.659$ D_{ibu}: the break-up date for Maqu D_{pl}: date when the air temperature goes above zero degrees D_{ibu} and D_{pl} stand for the numerical order as 1 Feb. is 1.	r: 0.715 r^2: 0.484 σ: 77.3%

Note: r represents the correlation coefficient of the MLR equation and r^2 is coefficient of determination. σ is the eligible ratio, and according to Hydrological Prediction Standard, the permissible error can be made by linear interpolation, and the value is 6 days. If the deflected date between simulation results and observation results is less than 6 days, the simulation result is eligible. The ratio of the eligible results to the whole simulation results is the eligible ratio.

Table 3 ANN model for freeze-up date and break-up date.

Station	Input factors	σ (eligible ratio)
ANN model for freeze-up date		
Huangheyan	D_{ne}, T_{ane}, Q, T_{aw}	70.0%
Jimai	D_{ne}, Q, T_{aw}	66.1%
Maqu	D_{ne}, D_{ne8}, T_{ane}, Q, T_{aw}	69.5%
ANN Model for Break-up Date		
Huangheyan	D_{pl5}, T_{ane}, Q	73.7%
Jimai	D_{pl7}, T_{ane}, Q	93.7%
Maqu	D_{pl}, T_{ane}, Q	90.9%

D_{ne}, T_{aw}, D_{pl5}, D_{pl7}, D_{pl}, D_{ne8}, D_{ir} has the exactly same meaning with those in MLR Model. T_{ane}: the accumulated negative temperature of certain days after D_{ne}. Q: average discharge of certain month.

Artificial neural network model

After normalizing the data, they are partitioned into training pattern, examine pattern and support pattern, which can be achieved by the multilayer preceptor in SPSS (see Table 3).

Analyses on the simulation result

The obtained results of simulations are shown in Figs 6 and 7. One can see from these figures that both the MLR and the ANN model can be identified as eligible. Under most circumstance, ANN model performs better than the MLR model as its eligible ratio is higher.

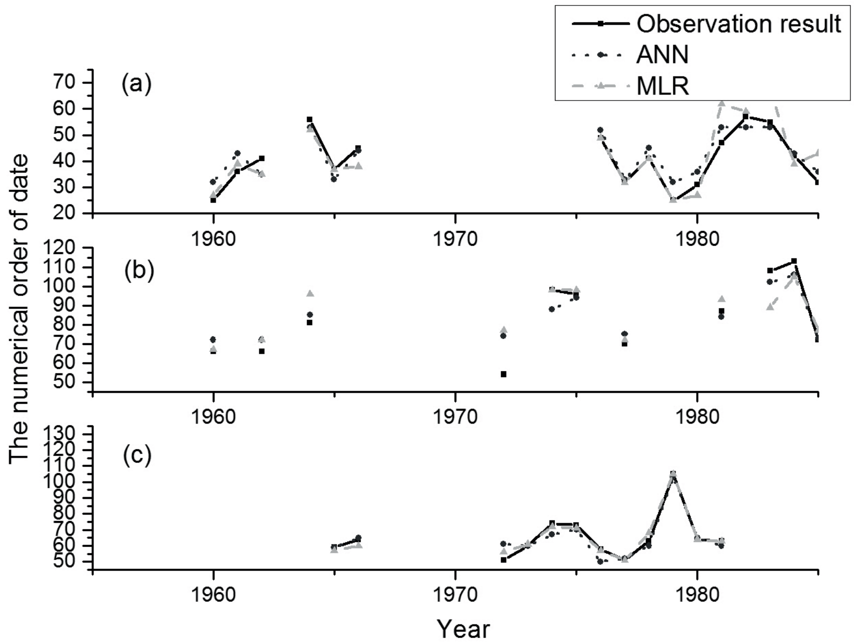

Fig. 6 Simulations and observations of freeze-up dates for Huangheyan, Jimai and Maqu.

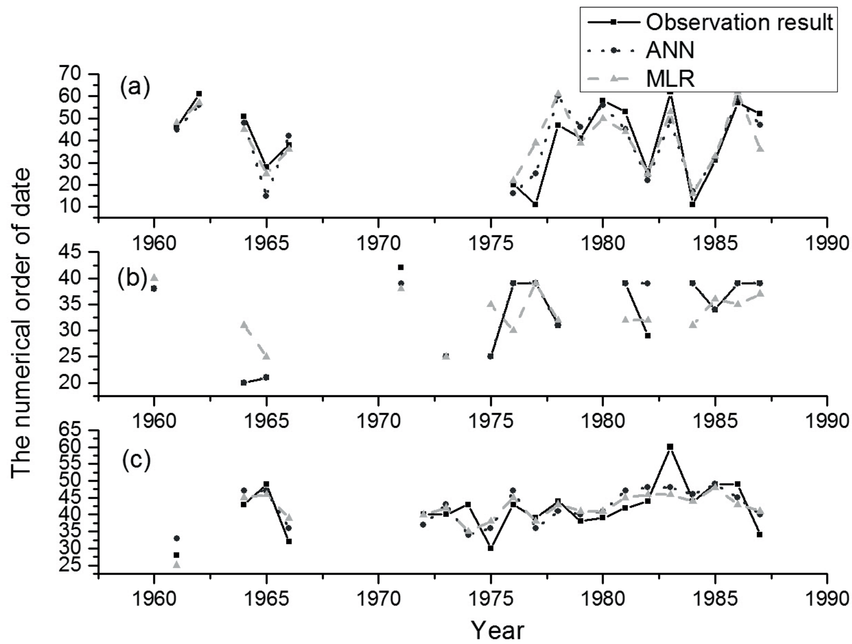

Fig. 7 Simulations and observations of break-up date for Huangheyan, Jimai and Maqu.

There are many cases where there are notable differences between the simulation and the observation results, which can be modified by further analyses and modification of the two models, plus new data and materials.

DISCUSSION

The main factors influencing the freeze-up and break-up date are air temperature, the volumetric discharge, and the channel conditions. Both the MLR model and ANN model can make a qualified prediction, but under most conditions, the ANN model is better. If more detailed ice data can be obtained and accessed, the model can be modified and improved, so as to be used on the whole reach. Many natural rivers, such as the Yellow River, are meandering rivers, their cross sections and planform morphology usually change frequently. The ice condition forecast for these kinds of rivers with the traditional models is very difficult, since the actual data about the rivers is usually unknown. Based on the use of the historical data, the ANN model with its merits as the map to nonlinear problems, satisfactory solutions to the ice condition forecast can be found.

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