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Palaeorunoff estimations achieved from palaeoclimatic information for the southwest part of the North China Plain: an attempt to apply a climatological approach to palaeohydrology

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Abstract: Palaeoclimatic scenario projecting annual temperature and annual precipitation is firstly formalized with data available and speculations for the southwest part of the North China Plain (35— 37°N, 115—119°E) during the last 25000 years. Then, with three regression equations relating annual runoff to annual precipitation and derived with data of modern hydrological and meteorological records, values of annual runoff are calculated in terms of the corresponding values of annual precipitation from this palaeoclimatic scenario for this region during this temporal interval. These results indicate that runoff is the most during 8000—3000 a B.P. and the least during 25000—12000 a B.P.; runoff occurring during 12000—8000 a B.P. and during 3000—0 a B.P. is less than the one occurring during 8000—3000 a B.P. and more than the one occurring during 25000—12000 a B.P.; and the runoff occurring during 25000—12000 a B.P., 12000—8000 a B.P., and 3000—0 a B.P. is respectively 43, 46 and 66 percent of the one occurring during 8000—3000 a B.P. Values of bankfull discharge for palaeochannels of the Yellow River flowing in this region during the same interval are calculated from available estimates of slope of stream-bed of these palaeochannels with a regression equation relating bankfull discharge to slope of stream-bed and ratios of bankfull-discharge are further calculated from these values for different groups of palaeochannel formed during different time spans embraced in this interval. To conduct a cross-check, these values and ratios of bankfull-discharge are compared to the corresponding values and ratios of runoff occurring during roughly the same time spans. The same direction and similar relative magnitude of changes of the surface water occurring in this region during the last 25000 years are indicated by these comparisons.

Key words: palaeorunoff; the southwest part of the North China Plain; palaeoclimate

Introduction

Runoff is that part of precipitation that appears in surface streams (Langbein, 1949). Its variations from place to place and from time to time are dominantly associated with corresponding variations in precipitation. Temperature, as it affects the intensity of the evapo-transpiration processes, also has a major influence on the spatial and temporal distribution of runoff. Thus it is likely to achieve crude estimations of runoff in terms of corresponding precipitation and temperature.

Runoff is also somehow influenced by vegetation, topography, soil, geology etc., and is the water that plays the principle role in fashioning and modifying the fluvial landscape. Therefore reconstructing regimes of runoff occurring in the past is significance of further understanding of ancient environments and their changes has been attempted (Schumm, 1965; 1967; Li, 1994).

This paper presents an initial attempt to estimate palaeorunoff regimes for the southwest part of the North China Plain (35—37°N, 115—119°E) during the last 25000 years. In such an attempt, utilizing regression equations relating mean annual runoff to mean annual precipitation for different ranges of mean annual temperature derived with climatological and hydrological data of the contemporary time, annual values of palaeorunoff were calculated from the corresponding estimates of past precipitation. Values of bankfull discharge were then calculated for the Yellow River acting in this region during the same period. Finally to conduct a cross-check, the reconstructed palaeorunoff regimes were compared to the palaeodischarge ones to see if the estimations of the two hydrological parameters would indicate the same or similar tendency of quantitative changes of

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surface water there and then.

1 Study region

The so-called "southwest part of the North China Plain" or "the North Shandong Plain" (35—37° N, 115—119° E) with which is dealt in this paper is a narrow stripe in Shandong Province, east mainland China. It is bounded on the north by Hebei Province and on the south by Henan Province.

A sub-humid continental monsoon climate has dominated in this region. Mean annual temperature is about 13.0℃. Average monthly temperature of January is − 3.0℃ and of July is 26.0℃. Mean annual precipitation is around 600 mm. Precipitation largely concentrates in June, July and August. Precipitation falling in July and August is usually more than 60 percent of annual one. Potential natural vegetation is deciduous broadleaf forest.

Mean annual runoff is some 50 mm in this region. Crossing this area, the Yellow River, the second largest river in China, the Majia River, and Tuhai River flow towards northeast and into the Bo Hai Sea (Fig. 1).

Topographically the terrain of the whole region slopes gently from southwest to northeast (Zhang, 1990a). As an integrated part of the North China Plain, one of the largest fluvial plains in east China, this region has been covered with alluvial sediments of great thickness since the late Pleistocene. The Yellow River and other rivers have flicked, migrated and changed their own courses since this geological period, leaving quite a lot of palaeochannels (Zhang, 1990a; 1990b).

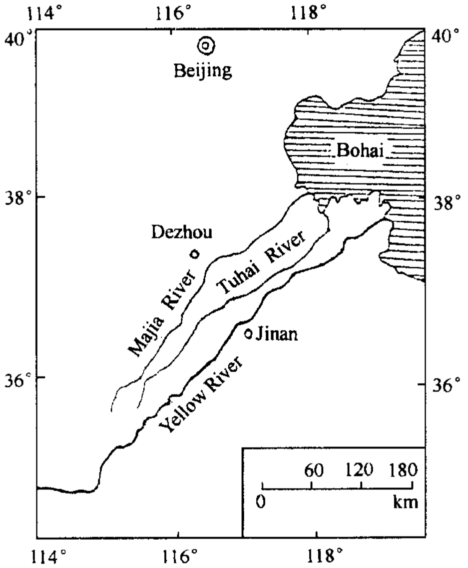

Fig. 1 The southwest part of the North China Plain, the study region

2 Reconstruction of palaeorunoff regimes

2.1 "Present" climatic parameters-runoff relationships and their potentials for estimations of "past" runoff

Langbein and others (Langbein, 1949) plotted a group of curves relating mean annual precipitation to mean annual runoff for six values of mean annual temperature using contemporary data of climatology and hydrology to generally demonstrate the effects of temperature and precipitation on runoff. Schumm (Schumm, 1977) slightly modified the four of these curves for 40°F (4.4℃), 50° F(10.0℃), 60°F(15.6℃) and 70°F (21.1℃) of mean annual temperature by adopting "mean annual precipitation" as abscissa and "mean annual runoff" as ordinate. Furthermore, Schumm (Schumm, 1977) argued that such kind of curves which are plotted with data of the modern climatological and hydrological records can be directly employed to postulate the Quaternary palaeorunoff if the corresponding past temperature and precipitation are known. This argument of Schumm's is apparently based on the principle of Uniformitarianism of "the present is the key to the past" and, as well as the accompanying curves, has attracted considerable attention from Quaternary researchers due to its potentials for Quaternary palaeohydrological studies (Gregory, 1983; 1996).

Schumm's argument has paved the way for developing a method of palaeorunoff reconstruction (Gregory, 1983; 1996). However, the applicability of these curves themselves modified and represented by him may be still rather limited in practical studies of palaeohydrology. These curves were virtually based on the data for only 31 drainage basins in the conterminous United States (Langbein, 1949) and are for only four values of mean annual temperature. Climatic regimes and their influences on runoff are diverse and complex during both the contemporary time and

Quaternary past. Thus the four curves may only partially manifest the climate-runoff connections due to the diversity and complexity.

A total of 41 regression equations relating mean annual runoff to mean annual precipitation, to mean annual precipitation and mean annual temperature, or the mean annual precipitation and water equivalence of snow cover were later derived with data of 30 years' records for 726 drainage basins in the United States, Australia, Zimbabwe, and Finland (Wang, 1995).

These drainage basins are under annual temperature of − 3.3℃—31.7℃ and annual precipitation of 51—4496 mm and are situated in areas of the following types of climate: (1) tropical rainforest; (2) tropical monsoon; (3) tropical wet and dry; (4) humid subtropical (east coastal humid subtropical); (5) mediterranean subtropical (west coastal dry subtropical); (6) marine west coast; (7) humid continental; (8) midlatitude dry (steppes); (9) continental subaractic (boreal).

These equations may be more universally applicable as they were derived using more data for more drainage basins under influences of more diverse and complex climates. To convenience the utilization of these equations in practical studies of palaeohydrology, applicable ranges of annual precipitation and annual temperature and types of climate were also listed with each of them (Wang, 1995).

2.2 Palaeoclimates

Palaeoclimatic knowledge is indispensable for utilizing the "present" climate-runoff relationships to reconstruct palaeorunoff regimes. Thus efforts were attempted to acquire the necessary palaeoclimatic information.

Zhao (Zhao, 1987) generalized results of pollen analysis for sediments from 10 drill holes and identified 7 climatic periods in terms of annual temperature for the North China Plain during the last 120000 years. Among them, the last 4 periods (Period 4, 5, 6 and 7) cover the span of the last 25000 years. According to this scheme of Zhao's, annual temperature was about 7.5—8.5℃ lower during 25000—12000 a B.P., 1.0—2.0℃ lower during 12000—8000 a B.P., and 2.0—4.0℃ higher during 8000—3000 a B.P. than it is today; during the period of 3000—0 a B.P., it has been slightly lower than present annual temperature, being 11.0—12.0℃. Wu *et al*. (Wu, 1992) postulated that annual precipitation was about 200 mm less than the modern annual precipitation in the North Shandong Plain during the Würm Glaciation. Zhong *et al*. (Zhong, 1983) investigated the Holocene peatlands in the North China Plain and estimated that annual precipitation was 500—600 mm higher during 8000—5000 a B.P. and 200—300 mm higher during 5000—2500 a B.P. than its contemporary counterpart in this region.

No quantitative data on annual precipitation are available for the early and late Holocene. More speculative estimations on annual precipitation are thus made for the two spans of the Holocene. The early Holocene is usually regarded a transition from the dry late Pleistocene to the wet middle Holocene. Therefore annual precipitation for the period of 12000—8000 a B.P. was speculated to be higher than the one for the late Pleistocene and lower than the one for the middle Holocene, about 90—95 percent of the modern annual precipitation. Since 3000 a B.P., climate has begun to gradually become drier. It is thus assumed that, for the period of 3000—0 a B.P., annual precipitation was lower than it was during the middle Holocene and higher than it is today, about 5—10 percent higher than the present annual precipitation.

With these estimates of annual temperature and annual precipitation and the framework of Zhao's scheme, a palaeoclimatic scenario is formalized for the study region (Table 1 and Fig. 2a and Fig. 2b).

Table 1 **Palaeoclimate and palaeorunoff calculations for the southwest part of the North China Plain during the last 25000 years**

		Period 7 (3000—0 a B.P.)	Period 6 (8000—3000 a B.P.)		Period 5 (12000—8000 a B.P.)	Period 4 (25000—12000 a B.P.)
			5000—3000 a B.P.	8000—5000 a B.P.		
Annual temperature,	Range	11.0—12.0	15.0—17.0	15.0—17.0	11.0—12.0	4.5—5.5
℃	Average	11.5	16.0	16.0	11.5	5.0
Annual precipitation,	Range	630—660	800—900	1100—1200	540—570	
mm	Average	645	850	1150	555	400
Annual runoff,	Range	165—184	167—210	310—367	112—129	
mm	Average	175	189	339	121	113
			264			
Equation used for calculating runoff values		$R = -129 + 0.318P + 0.000236P^2$ 5—(4) $r^2 = 79.1\%$; N:230	$R^{1/2} = 0.45 + 0.0156P$ 5—(3) $r^2 = 69.0\%$; N:183		$R = -129 + 0.318P + 0.000236P^2$ 5—(4) $r^2 = 79.1\%$; N:230	$R = -142 + 0.608P + 0.000071P^2$ 5—(10) $r^2 = 80.0\%$; N:159
In the equations,		Applicable range of annual temperature: 7.8—12.8℃	Applicable range of annual temperature: 13.3—18.3℃		Applicable range of annual temperature: 7.8—12.8℃	Applicable range of annual temperature: 4.4—9.4℃
P: annual precipitation, mm		Applicable range of annual precipitation: 203—3048 mm	Applicable range of annual precipitation: 102—2159 mm		Applicable range of annual precipitation: 203—3048 mm	Applicable range of annual precipitation: 51—3302 mm
R: annual runoff, mm		Mainly applicable to humid continental and temperate climates, but also applicable to semi-arid continental and Mediterranean climates	Mainly applicable to humid continental and temperate climates, but also applicable to semi-arid continental, Mediterranean, and wet and dry tropical climates		Mainly applicable to humid continental and temperate climates, but also applicable to semi – arid continental and Mediterranean climates	Mainly applicable to humid continental, temperate, and semi-arid continental climates, but also applicable to Mediterranean climate

2.3 Palaeorunoff calculations

The 'most appropriate' regression equations between annual precipitation and annual runoff for some specific ranges of annual temperature have to be firstly chosen from the 41 existing ones (Wang, 1995) to infer the palaeorunoff regimes from the corresponding palaeoclimatic information. It is the most ideal, for a specific period, to find such an equation which has the closest applicable ranges of annual temperature and annual precipitation and type of climate to the palaeoclimatic conditions of this period. However in reality understandings to palaeoclimate of a period are often limited only to inferences of annual temperature and annual precipitation and very little is known on climatic type and other details. On the other hand, many of these equations were actually derived with the data for drainage basins situating in areas of several types of climate which are not similar each other at all rather than in areas of one specific type climate or several similar types of climate (Wang, 1995). Therefore selections of regression equations are principally made on the basis of the closeness of applicable ranges of annual temperature and annual precipitation of equations to estimates of annual temperature and annual precipitation of these periods.

For the four periods with which are dealt, three equations, 5—(3), 5—(4) and 5—(10), are selected from the 41 ones (Wang, 1995) to calculate values of annual palaeorunoff. The three equations are from Group 5 or "Global" type of ones which were derived with a composite set of

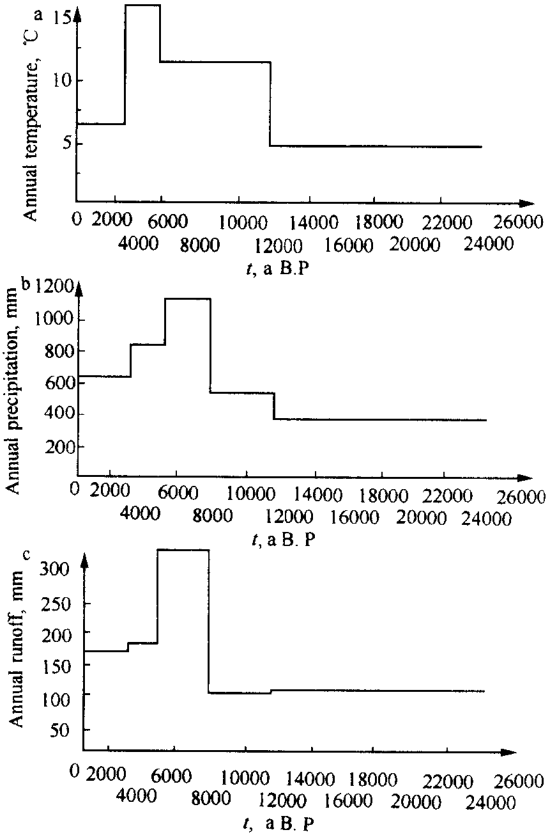

Fig.2 The southwest part of the North China Plain during the last 25000 years
a: reconstructed annual temperature; b: annual precipitation; c: annual runoff

data for the drainage basins in the conterminous United States, Australia, Zimbabwe and Finland. Compared to another four groups of equations which were derived only with data for the drainage basins respectively in the conterminous United States, Australia, Zimbabwe, and Finland and are thus respectively called "US Type", "Australia Type", "Zimbabwe Type" and "Finland Type" of equations, these "Global" type of equations may reflect more comprehensively climate-runoff associations of the drainage basins under influences of these specific ranges of annual temperature and annual precipitation. However statistically "comprehensiveness" or "synthesis" is often at the expense of "specificity" or "accuracy". Thus equations of Group 5 may somehow to a greater extent neglect or conceal the influences of more local factors, climatic (e.g. those associated with climatic type) and non-climatic, on runoff than another four groups of regression equation. Nevertheless, the selection of the three equations of "Global" type is virtually a rather mandatory choice which has to be made due to the scarceness of more specific knowledge on palaeoclimates occurring during these periods.

With these three chosen regression equations, annual values of palaeorunoff are calculated from the corresponding estimates of annual precipitation for the four periods (Table 1; Fig.2c).

Runoff occurring during the warm and wet Period 6 (8000—3000 a B.P.) or Megathermal was apparently much. In this period, although high temperature and resultant high evaporation might considerably reduce the water occurring on the surface, however precipitation was also simultaneously much and was capable of supplementing and maintaining the much surface water. Therefore there was much runoff then. Runoff was obviously less during Period 5(12000—8000 a B.P.) and during Period 7(3000—0 a B.P.) than during Period 6 (8000—3000 a B.P.), being only 46—66 percent of the runoff occurring during Period 6. Although precipitation was much less during Period 4 (25000—12000 a B.P.), nevertheless runoff was only slightly less than its equivalence of period 5 and Period 7's, being about 43 percent of Period 6's runoff, which is probably due to the low evaporation associated with low temperature.

3 Palaeochannels, palaeodischarge calculations, and comparisons of palaeodischarge to palaeorunoff

Three bands of palaeochannels of the Yellow River have been identified in this region (Zhang, 1990a; 1990b). These palaeochannels are either still exposed on the ground surface or buried with unconsolidated Quaternary deposits underground, stretching in the southwest-northeast direction.

Zhang (1990a; 1990b) divided the palaeochannels existing within the depth of 0—50m into three groups in terms of mainly geomorphological, sedimentological, and palynological characteristics (Table 2). With the 9 data of ^{14}C dating cited by Zhang (1990b), it is generalized that the three groups of palaeochannel, Group Ⅰ, Group Ⅱ and Group Ⅲ, were formed respectively during 25000—9400 a B.P., 9400—4900 a B.P, and 4900—0 a B.P. or, as Zhang (1990b) summarized, during the last stage of the late Pleistocene-early Holocene, the early Holocene-middle Holocene, and the middle Holocene-late Holocene. Furthermore, Zhang (1990b) postulated that the slope of stream-bed of the palaeochannels of Group Ⅰ, Group Ⅱ and Group Ⅲ is respectively 1.20/10000— 0.90/10000, 0.90/10000—0.70/10000 and 1.10/10000—0.95/10000 (Table 2).

Table 2 Palaeochannels* and estimates of bankfull discharge of the Yellow River in the southwest part of the North China Plain during the last 25000 years

Group of palaeochannel	Depth of palaeochannel, m	Age of palaeochannel, a B.P.	Slope of stream-bed	Bankfull discharge(Q_b), m³/s Range	Average	Equation used in calculating bankfull discharge
I	20—50	25000—9400	1.20/10000—0.90/10000	44668—79433	62051	$Q_b = 0.00585 S^{-2.01}$ In the equation, Q_b is the bank- full discharge, m³/s; S is the slope of stream-bed, m/m
II	8—20	9400—4900	0.90/10000—0.70/10000	79433—131826	105630	$r^2 = 90.3\%$; N:13 Applicable range of slope of stream-bed: 0.000066—0.0073
III	0—8	4900—0	1.10/10000—0.95/10000	53703—70795	62249	Derived by Cheetham (1980) with the data used by Leopold and Wolman (1957) and thus applicable only to braided-channel

* : Zhang, 1990b

It is possible to calculate values of hydrological parameters describing relatively high-probability flow events with equations relating these parameters to palaeochannel dimensions, sediment characteristics, gradients, and other field evidence (Barker, 1991) for alluvial rivers acting in the Quaternary past. One of such equations was derived by Cheetham (Cheetham, 1980) with the data used by Leopold and Wolman (Leopold, 1957).

Using this regression equation relating bankfull discharge (Q_b) to slope of stream-bed (S) (Cheetham, 1980), values of bankfull discharge are calculated for the three groups of palaeochannels (Table 2) from the estimates of slope of stream-bed of these palaeochannels (Zhang, 1990b).

As expected, the palaeochannel of Group Ⅱ formed during 9400— 4900 a B. P. which comprises the warm and wet middle Holocene have the largest bankfull discharge. The bankfull discharge is the least for palaeochannels of Group I formed during 25000—9400 a B.P. embracing the last stage of the late Pleistocene when it was cold and dry through being roughly the same to the one for the palaeochannels of Group Ⅲ formed during 4900—0 a B.P.

Table 3 Comparisons of runoff occurring in the southwest part of the North China Plain to bankfull discharge for the Yellow River flowing across the same region during the last 25000 years

Stage and group of palaeochannel*	R_N	Q_N
Stage Ⅰ (25000—8000 a B.P.)	117	
Group Ⅰ (25000—9400 a B.P.)		62051
Stage Ⅱ (8000—5000 a B.P.)	339	
Group Ⅱ (9400—4900 a B.P.)		105630
Stage Ⅲ (5000—0 a B.P.)	182	
Group Ⅲ (4900—0 a B.P.)		62249
$R_{\mathrm{II}}/R_{\mathrm{I}}$	2.90	
$Q_{\mathrm{II}}/Q_{\mathrm{I}}$		1.70
$R_{\mathrm{III}}/R_{\mathrm{II}}$	0.54	
$Q_{\mathrm{III}}/Q_{\mathrm{II}}$		0.59

* : Zhang, 1990a; R_N: average of annual runoff values for each one stage (mm) (N: ordinal number of stage); Q_N: average of bankfull discharge values for each one group of palaeochannel (m³/s) (N: ordinal number of group of palaeochannel)

With the average of annual runoff (Table 1), mean values of annual runoff are respectively calculated (Table 3) for three stages, Stage Ⅰ (25000—8000 a B. P.), Stage Ⅱ (8000—5000 a B.P.), and Stage Ⅲ (5000 - 0 a B. P.) which are roughly equivalent respectively to 25000—9400 a B.

P., 9400—4900 a B. P., and 4900—0 a B. P. when palaeochannels of the three groups were formed. These palaeorunoff averages of the three stages are compared respectively to the averages of bankfull discharge of the corresponding groups of palaeochannel (Table 2), as listed in Table 3.

Furthermore, ratios of Stage Ⅱ's runoff to Stage Ⅰ's and of Stage Ⅲ's to Stage Ⅱ's are respectively calculated (Table 3). Similarly, ratios of bankfull discharge of Group Ⅱ's palaeochannel to bankfull discharge of Group Ⅰ's palaeochannel and of bankfull discharge of Group Ⅲ's palaeochannel to bankfull discharge of Group Ⅱ's palaeochannel are also respectively calculated (Table 3). Then the ratios derived with runoff values of each two stages are respectively compared to the corresponding ones derived with values of bankfull discharge for each two groups of palaeochannel formed roughly during the intervals covered by the two correspondent stages (Table 3). As indicated by these values and radios tabulated in Table 3, calculations of both runoff and bankfull discharge show in fact the same direction and similar relative magnitude of hydrological change occurring in this region during the last 25000 years. From the last interval of the late Pleistocene-early Holocene to the early Holocene-middle Holocene, surface water remarkably increased. The water occurring on the ground surface during the early Holocene-middle Holocene might be 1.7 times or even 2.9 times as much as the one occurring during the last interval of the late Pleistocene-early Holocene. However, the surface water has apparently decreased from early Holocene-middle Holocene to the middle Holocene-late Holocene, the one of the later's probably only being 59 or even 54 percent of the former's.

Comparing the results of runoff calculations to the ones of bankfull-discharge calculations may virtually represent a cross- check to the two kinds of results as they are derived respectively climatologically and geomorphologically and thus with two mutually unrelated and independent approaches. The relative identity of the results of runoff reconstructions to those of bankfull-discharge ones, as shown by these comparisons, thus implies a relative confirmation to the reliability of the runoff reconstruction's results by the bankfull-discharge reconstructions and vice versa.

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