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Pollen Assemblage Features of Modern Water Samples from the Shiyang River Drainage, Arid Region of China

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Abstract: Pollen analysis of 30 modern water samples from the Shiyang River, an internal river system located between the Tengger and Badain Jaran deserts, Northwest China was carried out to examine the river's capacity to carry pollen and spores, and to assess the contribution of the water-borne pollen to pollen assemblages in lake sediments at the end of the river system. Results indicate the pollen assemblages in water samples consist of both local and upland pollen. Percentages of upland pollen reach 30% - 60%, and pollen assemblages in water samples do not indicate the nature of local vegetation at the sampling sites. Fluvial currents have the capacity to transport large quantities of pollen long distances, and the contribution of this fluvial transported pollen is relatively high. For example, percentages of *Picea* Dietr. pollen in water samples at sampling sites 130 km and 145 km away from *Picea* forests reach 16.5% and 7.7%, respectively. Fluvial pollen transport occurs primarily during flood periods, and pollen concentrations from the flood samples are 17.1 - 12.5 times those from normal fluvial flow. Reservoirs affect pollen transportation since pollen is deposited at reservoir inlets and pollen concentrations are much reduced at reservoir outlets. Human activity can thus change natural features of pollen transportation and deposition. The main factors influencing pollen concentrations and assemblages are sampling time, sampling location, and rainfall intensity.

Key words: pollen analysis, modern river water, Shiyang River, arid region of China

The transportation and deposition processes of water-borne pollen must be understood before the environmental signals of pollen data from rivers, lakes and oceanic sediments can be used to reconstruct palaeoenvironments, since almost all pollen data from rivers, lakes and ocean sediments have a strong relationship with fluvial flow[1,2]. Previously, most attention has been paid to air-borne pollen. Investigations involving transportation and deposition processes of air-borne pollen have covered almost all geographic areas and different time scales and seasons[3]. Conversely, there are few reports from anywhere in the world concerning water-borne pollen[3], and there is only one brief report from China[4]. Previous studies have shown that river flow has enough capacity to transport large quantities of pollen and spores long distances[1,2,5,6], and that pollen and spores transported by fluvial currents can be the main source of pollen in alluvial sediments[6,7], open (supplied by streams) lake sediments[8 - 11], and delta sediments[2]. However, these conclusions were all drawn from analyses of sediments, with few firsthand investigations of water samples. Studies of the water transport of pollen and spores are therefore essential, not only to provide correct reconstructions of palaeoecological conditions, but also to contribute to basic aspects of pollen analyses[3,12,13].

Numerous studies have recently focused on the arid lands in northwest China at the center of the Eurasian continent, because they are sensitive to environmental change[14 - 16]. Pollen records from lakes in the arid region are some of the best proxies from the Eurasian continent for vegetational histories and environmental responses to global climate change. However, most lakes in the arid region of northwest China are open lakes supplied by rivers originating from high mountains. These rivers pass through multiple vegetation zones before terminating in the desert lakes. Previous studies indicate that 85% - 97% of pollen in pollen assemblages from surface samples of open lakes come from rivers[8,9], and that percentages of extra-local pollen in the open lakes are higher during periods of local vegetational degeneration[10].

The interpretation of open lake pollen data from deserts is also extremely difficult because strong winds and flash floods are very common and can carry pollen long distances. Additionally, local vegetation in deserts lands is so sparse that the amount of local pollen is very small. When mixed with extra-local pollen, local pollen in pollen assemblages may be overwhelmed[17]. Our research in desert lake sediments indicates pollen assemblages are dominated by conifer tree pollen, and that this dominance was not the result of a drop of conifer forest tree lines[18]. A similar case occurs in another Holocene section in the Shiyang River basin[16]. We analyzed 30 modern water samples from the Shiyang River to examine the capacity of

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the river water in carrying pollen and spores, and to assess the contribution of the water-borne pollen to the pollen assemblages in the lake sediments at the end of the river system.

1 Setting

The Shiyang River drainage lies on the northern side of Qilian Mountains, at the eastern end of Hexi corridor. During the late Pleistocene and Holocene there was a palaeolake at the end of the drainage. A flood plain and gobi desert occurs between the southern margin of the palaeolake and northern margin of the Qilian Mountains. An alluvial plain and sandy desert are north of the palaeolake. The southern portion of the drainage is in a cool temperate semi-arid climate, while the middle and northern portions are in a temperate arid climate. From south to north, the distribution of modern vegetation is strongly related to elevation (Fig.1): perennial snow and ice zone (> 4 500 m); cushion-like vegetation zone (4 500 – 3 800 m); meadow zone (3 800 – 3 500 m); alpine shrub zone (3 500 – 3 100 m); *Picea* and *Sabina* forest zone (3 100 – 2 500 m); mountainous grassland zone (2 500 – 2 350 m); desert grass zone (2 350 – 2 000 m) and gobi-sand desert zone (< 2 000 m)[19, 20]. The Shiyang River, with an annual mean flux of 1.336 3 × 10^{10} m^3, originates in the Qilian Mountains and disappears into the desert at the northern end of the drainage. By the 1950's, the paleaolake was dry because human use of river water increased[15]. There are currently several reservoirs on the upper and middle reaches of the Shiyang River drainage (Fig.1).

2 Methods

On April 6th to 9th, 2000, before the *Picea* Dietr. pollen bloom, and on July 10th to 17th, 2000, during the late *Picea* bloom, 10 and 20 samples were taken, respectively. Sampling details are shown in Table 1. Water samples for pollen analyses were poured directly into plastic tanks with a volume of 2.5 L. After a tablet of *Lycopodium* L. spores with 12 542 grains was put into the tank, it was sealed, and quickly transported to laboratory where the water samples were pretreated by HF and 1∶9 (96% H_2SO_4 to acetic anhydride) mixed liquid after filtering through 6 μm mesh. In most cases, over 300 grains of pollen or spores per sample were identified, except for a few samples taken under periods of normal fluvial flow and in samples collected at the outlet of reservoirs.

3 Results and Discussion

Forty-three taxa were identified: *Picea*, *Sabina*, *Pinus*, *Cedrus*, *Juniperus*, *Betula*, *Ulmus*, *Quercus*,

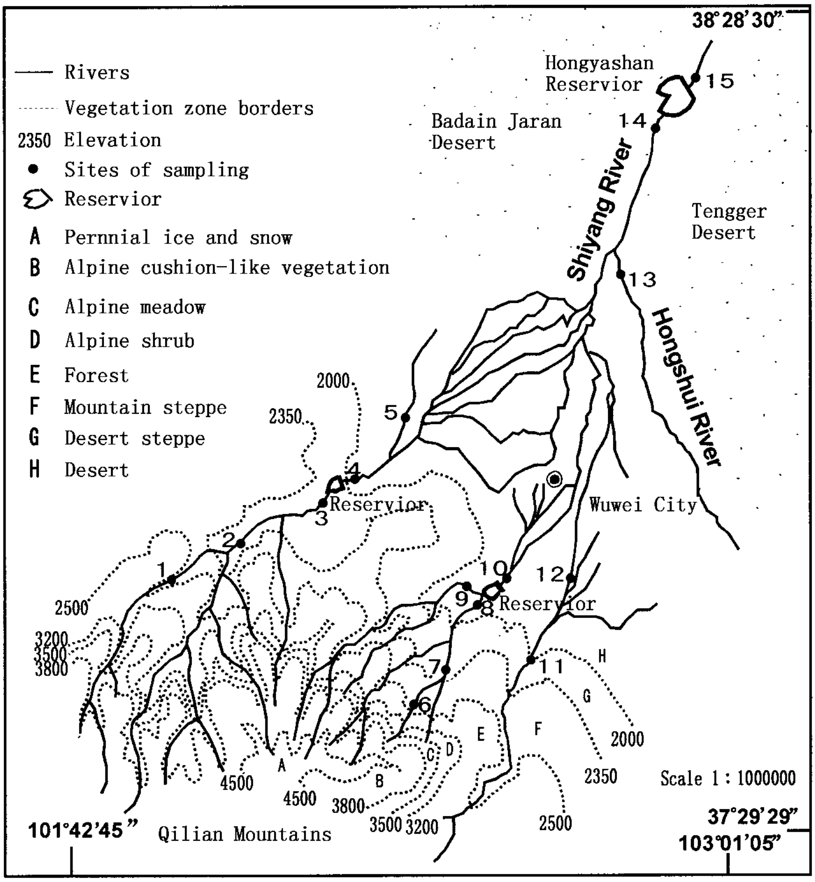

Fig.1. Location of the Shiyang River and sampling sites.

Table 1 Information about the samples from the Shiyang River drainage

Sampling sites	Latitude and longitude of the sampling sites	Vegetation zone of sampling sites	Sampling time*	Samples code	Pollen concentration (grains/L)
1	37°49′ 43″-101°57′17″	Mountain steppe	08-04-2000, BR	WI-1	718
2	37°53′18″-102°07′15″	Desert steppe	08-04-2000, BR	WI- 2	1 253
3	37°54′54″-102°12′52″	Desert steppe	08-04-2000, BR	WI - 3	139
			09-04-2000, AR	WI -8	1 736
			12-07-2000, AR	WII - 3	776
			16-07-2000, AR	WII - 10	1 263
4	37°55′ 49″-102°15′31″	Desert	08-04-2000, BR	WI - 4	14
			09-04-2000, AR	WI - 9	20
			12-07-2000, AR	WII - 4	5
			16-07-2000, AR	WII - 20	28
5	37°59′ 28″-102°20′11″	Desert steppe	12-07-2000, AR	WII - 5	105
6	37°38′ 21″-102°21′32″	Mountain steppe	12-07-2000, AR	WII - 1	10 714
7	37°40′ 28″-102°25′21″	Desert steppe	12-07-2000, AR	WII - 2	790
8	37°46′ 57″-102°29′07″	Desert	12-07-2000, AR	WII - 6	3 184
			16-07-2000, AR	WII - 11	1 828
			08-04-2000, BR	WI - 10	297
			09-04-2000, AR	WI - 6	5 100
9	37°47′ 48″-102°28′12″	Desert	16-07-2000, AR	WII - 12	941
10	37°48′ 45″-102°31′57″	Desert	12-07-2000, AR	WII - 7	430
			16-07-2000, AR	WII - 13	15
			19-07-2000, AR	WII - 16	14
			09-04-2000, AR	WI - 7	42
11	37°42′ 48″-102°33′49″	Desert steppe	12-07-2000, AR	WII - 8	3 504
			16-07-2000, AR	WII - 14	13 319
			09-04-2000, AR	WI - 5	4 803
12	37°48′ 07″-102°39′11″	Desert	12-07-2000, AR	WII - 9	1 068
			16-07-2000, AR	WII - 15	102
13	38°12′ 06″-102°46′20″	Sandy desert	17-07-2000, AR	WII - 17	39 285
14	38°21′ 30″-102°48′54″	Sandy desert	17-07-2000, AR	WII - 18	9 507
15	38°24′ 47″-102°53′14″	Sandy desert	17-07-2000, AR	WII - 19	219

BR, before rain; AR, after rain.

Populus, *Salix*, *Acer*, *Juglans*, Oleaceae, Rosaceae, Leguminosae, *Corylus*, Rhamnaceae, Tamaricaceae, Elaeagnaceae, Caprifoliaceae, Berberidaceae, Ericaceae, Gramineae, Compositae, Chenopodiaceae, *Artemisia*, *Polygonum*, Cyperaceae, *Humulus*, Malvaceae, Caryophyllaceae, *Stellera*, Cruciferae, Ranunculaceae, Umbelliferae, Polemoniaceae, *Nitraria*, *Calligonum*, *Ephedra*, Plumbaginaceae, Zygophyllaceae, *Typha*, *Selaginella*, and *Polypodium*. The percentages of principal taxa in the high concentration samples are displayed in Table 2. Pollen percentages were calculated by total taxa although the amount of *Typha* pollen is too low to influence the results of pollen analyses.

Pollen assemblages do not reflect the local vegetation at the sampling sites. The principal taxa can be divided into four pollen sums based on the relationship between the sampling sites and the distribution of modern vegetation and pollen sources. The first sum is extra-regional pollen such as *Cedrus*, etc, with too low percentage; the second is local pollen such as Tamaricaceae, Elaeagnaceae, Plumbaginaceae, *Nitraria*, *Calligonum*, *Ephedra*, *Zygoghyllum*, *Typha*, etc; the third sum is upland pollen, such as, *Picea*, *Sabina*, *Pinus*, *Juniperus*, *Betula*, *Salix*, *Acer*, *Corylus*, Caprifoliaceae, Berberidaceac, Cyperaceae, Ericacea, *Selaginella*, *Polypodium*, etc; the fourth sum is regional pollen such as Rosaceae, Leguminosae, Gramineae, Composita, Chenopodiaceae, *Artemisia*, *Polygonum*, etc, from plants which grow widely and are hard to identify to a source, upland or local. Almost all samples are from the desert vegetation zone except for two samples from sites 1 and 6. However, the pollen assemblages in all samples consist primarily of two kinds of pollen or spores: one is from the uplands and includes the third sum and a portion of the fourth pollen sum, the other is from local vegetation and includes the second sum and reminder of the fourth sum. But, the percentages of the second sum in each pollen assemblage (Table 2) reach 30% – 60%, it is so high that assemblages are not coincident with local desert vegetation. This case is similar to those from the Delaware and Mississippi rivers, where the pollen assemblages in water samples from the lower reaches and delta reflect all drainage vegetation rather than local vegetation[1,21].

It must be stressed that at least about 30% – 60%

Table 2 Pollen percentages in the main water samples from the Shiyang River drainage

Pollen	Code																
	WII-1	WII-2	WII-6	WII-7	WII-8	WII-9	WII- 10	WII- 14	WII- 11	WII- 12	WII- 17	WII- 18	WI-1	WI-2	WI-5	WI-6	WI-8
Sabina	0.9	2.2	2.5	13.6	4.9	1.2	1.4	0.3	1.4	2.7	2.2	1.0	17.1	10.3	8.1	10.6	17.9
Picea	30.7	28.9	28.5	4.5	24.4	18.4	41.7	50.5	17.9	10.5	21.4	9.0	17.2	17.2	14.2	8.2	7.2
Pinus	4.4	1.1	2.5	0.0	6.1	20.0	5.6	5.3	3.6	4.7	13.4	4.1	12.5	1.7	10.0	5.3	0.0
Betula	18.7	2.2	4.5	4.5	6.1	3.2	2.8	0.7	3.6	3.5	2.7	2.1	1.6	17.2	3.3	0.6	1.4
Salix	1.3	1.1	1.2	0.0	1.2	0.8	0.0	0.0	1.4	2.0	0.7	0.7	6.3	10.3	3.3	1.2	0.5
Quercus	0.0	0.0	0.8	4.5	1.2	0.4	2.8	0.0	0.0	1.5	0.0	0.3	0.0	0.0	0.0	1.2	0.0
Rosaceae	2.7	0.0	3.7	4.5	4.9	1.6	4.2	1.3	0.7	2.3	1.8	1.0	3.1	5.1	0.5	1.2	0.0
Leguminosae	1.3	1.1	0.0	0.0	2.4	0.4	0.0	0.3	3.6	2.7	0.7	0.0	0.2	0.3	0.1	0.1	0.2
Rhamnaceae	0.9	0.0	0.0	0.0	1.2	0.0	1.4	0.0	0.7	0.6	0.0	0.0	1.6	3.4	1.4	0.6	0.0
Berberidaceae	0.4	1.1	0.4	0.0	1.2	0.0	0.0	3.3	2.1	0.4	0.0	0.3	1.6	0.0	0.5	0.0	0.0
Ericaceae	1.3	0.0	0.0	4.5	1.2	0.4	2.8	0.3	0.7	2.1	0.0	0.7	0.0	0.0	0.0	1.2	0.0
Gramineae	16.9	35.6	13.2	22.7	2.4	9.6	13.9	28.9	20.0	26.3	18.8	15.6	4.7	3.4	4.3	11.1	8.7
Cyperaceae	1.3	1.1	2.5	0.0	8.5	5.6	1.4	2.0	1.4	2.2	4.0	1.7	1.6	0.0	0.5	0.0	0.0
Compositae	1.8	3.3	4.1	9.1	7.3	5.2	2.8	3.0	14.3	11.2	13.4	12.8	3.1	0.0	4.7	8.8	2.9
Artemisia	2.7	4.4	18.6	18.2	6.1	17.2	4.2	0.0	5.0	13.1	6.5	14.9	6.3	6.9	20.4	20.6	22.2
Chenopodiaceae	4.4	5.6	11.2	4.5	4.9	8.4	4.2	2.0	13.6	8.7	5.1	16.3	4.7	3.4	15.6	13.5	16.4
Polygonum	5.8	0.0	1.7	0.0	0.0	1.2	1.4	0.7	1.4	1.4	0.2	0.5	0.0	1.7	1.9	1.4	0.0
Humulus	1.8	2.2	0.8	4.5	0.0	2.0	0.0	0.7	2.9	1.2	1.1	0.7	4.7	0.0	1.4	0.0	0.0
Stellera	0.4	1.1	0.8	0.0	6.1	0.0	1.4	0.0	0.7	0.0	0.4	0.0	0.0	0.0	0.5	1.8	2.9
Polemoniaceae	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	1.5	0.0	0.0	0.0	0.0	0.6	0.0
Ranunculaceae	0.0	0.0	0.0	0.0	2.4	0.0	1.4	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nitraria	0.9	2.2	0.8	0.0	2.4	1.6	1.4	0.0	0.0	0.0	2.2	8.7	4.7	0.0	4.3	4.1	9.7
Ephedra	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	2.4	1.6	0.0	0.5	0.0	1.9
Zygoghyllaceae	0.0	0.0	0.0	4.5	0.0	0.4	0.0	0.0	0.7	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.5
Typha	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.5	0.0	1.9
Polypodium	0.0	4.4	0.4	0.0	2.4	0.0	1.4	0.0	0.0	1.0	1.0	0.8	1.6	0.0	0.9	0.0	0.0
Unknown	0.0	1.1	0.0	0.0	0.0	0.0	2.8	0.0	0.0	0.2	0.7	0.3	0.2	0.4	0.1	0.8	0.8
Upland pollen*	59.0	37.7	42.9	31.6	43.9	50.0	59.9	62.1	35.6	30.6	45.4	20.7	59.7	56.7	39.9	28.0	27.0

*, the pollen from upland vegetation; the second pollen sum described in the text.

Table 3 Pollen assemblage of water and surface soil samples from sampling sites No.13 and 14

Samples		1	2	3	4	5	6	7	8	9	10	11	12	13	14
NO.14	W	9.0	4.1	1.0	2.1	1.7	0.8	17.6	12.8	15.9	19.3	0.5	0.6	8.7	0.0
	SS	1.3	2.6	0.4	1.0	0.1	0.1	6.9	35.1	2.6	3.1	1.8	25.1	8.5	7.8
NO.13	W	21.4	13.4	2.2	2.7	4.0	1.0	18.8	13.4	6.5	5.1	0.2	2.2	2.2	1.4
	SS	5.1	8.1	0.3	0.1	0.1	0.0	5.5	5.2	0.1	3.0	19.1	9.1	24.6	15.7

W, water sample; SS, surface soil; 1, *Picea*; 2, *Pinus*; 3, *Sabina*; 4, *Betula*; 5, Cyperaceae; 6, *Polypodium*; 7, Gramineae; 8, Compositae 9, *Artemisia*; 10, Chenopodiaceae; 11, *Polygonum*; 12, Elaeagnaceae; 13, *Nitraria*; 14, *Zygoghyllum*.

of pollen from the desert sampling sites is upland pollen in the Shiyang River drainage, and that, as many studies have shown, it is essential to examine the source, transport, and depositional processes of pollen before pollen data are used to reconstruct palaeoenvironments[11,12,22-24].

Pollen concentration and assemblage varyed greatly after the river passes through the reservoirs. The samples collected at the inlet of reservoirs have higher pollen concentrations than those did at the outlet of reservoirs. The pollen concentrations in samples at the outlet are so low that some do not reach 50 grains/L. In the Shiyang River drainage, it is clear that human activities, such as reservoir construction, change the way that pollen is transported and deposited. Additionally, this suggests that lakes at the middle of a river are very similar to reservoirs at the middle reaches. As a result, pollen data from these kinds of lakes must be used cautiously to reconstruct palaeoenvironments, since great numbers of pollen in pollen assemblages from these lake sediments come from fluvial flow and do not indicate the nature of local vegetation.

Fluvial flow can transport large quantities of pollen long distances. Normally, upland pollen in the water samples can reach the water sampling sites either by fluvial or aeolian transport. Theoretically, the additional upland pollen in water samples transported by fluvial flow should equal the percentage of upland pollen from the water samples minus that from surface soil samples. For example, percentages of Picea pollen from surface soil samples at the sampling site 13 and 14 are only 5.1% and 1.3%, that from water samples are 21.4% and 9% (Table 3), respectively. These results are also documented in previous studies that indicate *Picea* pollen is poorly dispersed by air[25,26]. The differences in *Picea* pollen percentages, between water and surface soil samples of 15.3% and 7.7%, respectively, are the contribution of fluvial flow. The distances between the lower tree line and both sampling sites are 130 km and 145 km, respectively. Sample WII-17 is from fluvial flow under natural conditions, and 45% of pollen assemblage is upland pollen. Sample WII-18 is from fluvial flow from both undisturbed rivers and rivers with reservoirs in their upper reaches, so its percentage of upland pollen is relatively lower. Table 1 shows that pollen concentrations from fluvial flow are so high that of some samples reach 9 507 to 39 286 grains/L. A brief calculation of the mean flux of the Shiyang River drainage and mean pollen concentration suggests almost 1.363 × 1 015 pollen grains should be transported to the end of the river per year. Although the calculation is approximate, the rough results are also documented by other records[1,2,5,6.22,27]. These results from the Shiyang River drainage are similar even during seasons when pollen is not being produced, and when samples are collected near the riverbanks. Normally, the pollen concentrations in samples taken in the season of pollen production and from the sites in the center of the river are higher[2].

The main factors influencing pollen concentrations are sampling time, intensity of rainfall and sampling sites. We found that in the Shiyang River drainage, the primary period of pollen transport is during flood periods, a result similar to that found by previous studies[1,4]. Pollen concentrations in water samples from flood samples are higher than those from normal flow. For example, pollen concentrations in the flood samples from the site 3 in the April, 2000, were 12.5 times of that of normal flow. In site 8, they were 17.1 times higher. High pollen concentrations in the flood samples are due to surface flow caused by rainfall sweeping pollen deposited on the ground into the main river stream. Table 1 also shows that at the same sampling sites, pollen concentrations in the April samples were higher than those in the July samples, and the percentages of local plant pollen in pollen assemblages in April samples were more than those in July samples. This may be caused by differences in plant blooming seasons, sampling time, and periods of rainfall. The blooming season of upland plants lasts from early June to the end of July. At lower elevations, however, desert vegetation blooms from early spring to late autumn. Samples collected in April were taken from fluvial flow caused by the first heavy rain of spring and therefore contained pollen deposited from the previous autumn to sampling time. Samples collected in July were taken after a summer rain and during the period when upland plants bloom. As a result, local pollen in the April samples is greater than that in the July samples.

In our study, pollen concentrations are associated with intensity of rainfall rather than with the sand concentration in the water samples. This result is unlike those from the Yellow River[4] and the Mississippi River[1]. For example, sand concentrations in samples WII-18 and WII-17, both with high pollen concentrations, are 4.8 g/L and 5.1 g/L, respectively; but in samples WII-1 and WII-14, also with high pollen concentrations, are 0.3 g/L and 0.5 g/L, respectively. These results are due to differences in plant coverage and the capacity of the ground surface to resist erosion at the sampling sites where pollen and sand went into the rivers. Samples WII-1 and WII-14 are from the sampling sites in the mountain and desert steppe vegetation zones, respectively, and local plant coverage is relatively high and the resistance of the ground surface to erosion is strong. Conversely, samples WII-1 and WII-14 are in the sand desert vegetation zone, where the ground surface has little resistance to erosion. The sand concentrations in both samples are therefore high. Under similar natural conditions, the higher intensity of rainfall, the higher the pollen concentration, since more pollen grains are swept into the river by surface flow due to intense rainfall.

4 Conclusions

A. The pollen assemblages in water samples collected under natural conditions consist of two portions, local and upland pollen, with percentages of upland pollen constituting 30% – 60% or more of the pollen assemblages. The pollen assemblages in water samples do not indicate the nature of vegetation near sampling sites.

B. When rivers pass through reservoirs, almost all pollen is deposited in the reservoir sediments. Human activity can thus change the nature of pollen transportation and deposition.

C. Fluvial currents have enough capacity to transport large quantities of pollen long distances. Calculations suggest that about 1.363×10^{15} pollen grains have been transported to the middle and end of the Shiyang River drainage per year. The contribution of fluvially transported pollen is relatively high. For example, percentages of *Picea* pollen in water samples at sampling sites 130 km and 145 km away from forest reach 15.5% and 7.7%, respectively. Fluvial transport of pollen occurs mainly during flood periods, and pollen concentrations in flood samples are 17.1 – 12.5 times of those in samples collected during periods of normal fluvial flow.

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干旱区石羊河流域河水孢粉组合特征

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摘要： 石羊河流域初春和仲夏两季不同地点，洪水期、平水期30个河水样孢粉分析显示，没有人类影响的情况下，河水样孢粉组合是由河流上游径流区的植物孢粉和采样点附近植被孢粉组成的，前者在孢粉组合中至少占30%～60%。河水搬运孢粉的能力非常强，可长距离、大量地搬运孢粉。孢粉组合中河水贡献孢粉的含量较高，如：云杉属(*Picea* Dietr.)花粉河水的贡献率在中下游可达16.5%和7.7%。采样时间、地点影响河水的孢粉组合和浓度，洪水期是孢粉搬运的主要时期。河水经过水库后，其中孢粉绝大多数沉积在水库中。

关键词： 孢粉分析；现代河水；石羊河；干旱区

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