

Drinking water from Chinese rivers: challenges of clarification

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ABSTRACT

Despite an age-old preference in China to use spring or well water as drinking water, turbid waters from large rivers (Huanghe, Changjiang, Zhujiang, Hanjiang) have to be used for this purpose by the less privileged. Landslides and an increase in sediment loads in rivers are affected by population growth and deforestation. Clarification is required for shorter periods or throughout the year. Traditional clarifiers have been recorded since the 2nd century AD. Gelatinous and mucilaginous materials acting as adsorbents and coagulants of various efficiencies are identified and assessed. Some active substances are also known elsewhere. Certain materials contain toxic substances. Apricot kernels were later also used as a coagulant for turbid Nile water. Alum, also detected as a clarifier by humble Chinese, was chosen by engineers worldwide for use as a coagulant in waterworks. The need for clarified river water increases. Modern Chinese waterworks use aluminium polymers of their own production. Assistance is required for rural people in poor, remote counties without access to public water supplies. Primary school teachers could learn to monitor, in their communities, semi-quantitative clarification at the household level according to simplified water coagulation worked out for *Moringa* seeds.

Key words | alum, low-class achievements, natural clarifiers, river sediments, simplified technologies, waterworks coagulation

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INTRODUCTION

China has serious problems of silting in its large rivers and more than 7,000 small river basins in areas with soil erosion (Ding 1992, p. 37). Annual changes in river water – from a drastic deterioration of colour and physico-chemical quality during the rainy seasons to a return to original clarity or low turbidity – seem to have encouraged early attempts in Asia and Africa to speed up the slow natural processes of spontaneous sedimentation. The oldest references to the traditional use of clarifying materials in India and China are from the first centuries AD (Jahn 1977, p. 121; 1994, p. 45). The further development of water clarification in China is known from scattered records made by Chinese monks, scholars and foreign visitors who have observed the life of poor people.

The upper classes tried as long as possible to consume only spring or well water.

This paper aims to investigate the hydrological, environmental and socio-economic background affecting the choice of clarifiers for the silt-laden waters of the Huanghe, the Changjiang, and rivers in Guangdong, to identify quoted materials and to assess their efficiency and health risks. This is not only of academic interest but also important for present guidance. The work is based on studies of literature, correspondence with historians, sedimentologists and engineers in China and other countries, research by the author in tropical countries of Africa, Asia and Latin America, and visits to Guangdong, Fujian, Hainan (in 1992) and Macao (1996).

HYDROLOGY, SEDIMENTS AND TURBIDITY FLUCTUATIONS

Changjiang and Huanghe

Most rivers in central China flow from west to east. The longest are the Changjiang ('long river', in Europe often called Yangtze for the whole course of the river[†]) and the Huanghe or Yellow River (outlets: Yellow and Bohai Sea). Both start with frozen reaches in the Qinghai-Tibet Plateau, a frigid alpine steppe at an altitude of about 4,000 m. Only their source rivers have crystal-clear water. During their eastward passage through areas with intense soil erosion, the amount of sediment acquired is higher in the Huanghe, which is the muddiest river in the world. The two rivers differ also in the average annual volume of run-off to the sea; only $56 \times 10^9 \text{ m}^3$ in the Huanghe, compared with $1,000 \times 10^9 \text{ m}^3$ in the Changjiang.² The great run-off of the Changjiang is due to the annual precipitation in the areas along the river's course, increasing from 250 to 500 mm at the source to 800–1,800 mm below Yichang in the middle reaches. The Huanghe mainly flows in arid and semi-arid zones. Since the average annual precipitation in its basin is 478 mm, only a relatively small amount of water is available to carry a very heavy sediment load (Lin & Li 1986, pp. 1, 11). In Henan, where this load is greatest, the *Huanghe* is a typically unstable 'wandering river' prone to bank erosion and frequent channel-shifting. After large amounts of sediment have been deposited, the clay particles from the 'wash load' can settle and cover the non-cohesive and easily eroded silt and sand on the riverbed with a cohesive protective layer, which prevents easy formation of new branches. The lower Huanghe enters Shandong as a stable slow-flowing 'anabranching or meandering river'. The middle and lower Changjiang belongs to the same type (Wan & Gao 1994, p. 159). Since the Changjiang has as many as 48 tributaries (Lin & Li 1986, p. 2), their water quality can have great effects. The highest turbidities and the coarsest sediments are found in the upper reaches in Central Sichuan because purplish soil from rolling hills is washed into the main stream and also comes with the Minjiang and other tributaries (Zuo & Xing 1992, p. 164). As the river flows east,

the suspended matter decreases (Table 1). The maximum value of suspended solids in Changjiang water (23,000 p.p.m.) compares with the average maxima in the Blue Nile at Omdurman (Jahn 1977, p. 120). The self-purification of the Changjiang, however, is much less. The Blue Nile is almost completely clear in January and February (turbidity at Soba: 3 FTU (Jahn & Omer 1984, p. 151)). The fine silt and clay fraction of sedimentological records roughly corresponds to turbidity measured in terms of 'suspended solids' in waterworks (units: p.p.m.; mg/l). The laboratory of the Huanghe waterworks in Jinan found, for example, average annual fluctuations of 800–10,000 p.p.m. in recent years (Ch. Xiu, personal communication 1996), which is rather similar to the sedimentological records quoted in Table 1. Measurements of turbidity by nephelometry are strongly influenced by the chemical nature of the particles. The method involves comparing the transmission of light through a Formazin Standard Suspension to that through the water sample (units: NTU or FTU).³

The name Huanghe refers to the yellow colour of its sediment. The river takes up 70% of this load when passing through the Loess Plateau in Gansu and Shaanxi where 10,000 tons of soil per square kilometre are lost by erosion each year. The loess is carried by the wind from the Gobi and other deserts of Central Asia and Mongolia, and consists of silt-size grains loosely cemented by calcium carbonate (Zuo & Xing 1992, 130 ff.). The main source of the Huanghe's natural pollution with arsenic is also the Loess Plateau. The gradual ninefold increase of this pollutant towards the lower reaches is due to sediments on the river banks which contain arsenic (Shandong report 1982, p. 192). Assessments of the Huanghe's sediment load are already found in old sayings:

One dan (hectolitre) of Huanghe water contains six dou (decalitres) of silt

(Zuo & Xing 1992, p. 127);

Only once in a thousand years does the Yellow River become clear for a single day

(Eberhard 1987, p. 90).

The maximum-recorded sediment so far in the Huanghe has been 651 kg/m^3 (Zuo & Xing 1992, p. 127). There is 'pulsating flow' and virtual clogging up in certain small tributaries due to 'hyperconcentrations' up to

[†]Superscript numbers refer to the Notes on page 26.

Table 1 | Sediment load and turbidity of some important Chinese rivers used for urban and rural water supplies*

River	Length (km)	Annual silt discharge (tons/yr)	Suspended solids (ppm) or turbidity (NTU)		
			Minimum and maximum	Average	
				Summer	Winter
Changjiang (Long River)	6,300	500 million		(ppm)	
Upper stream at Chongqing, Sichuan			100–23,000	1,000–2,000	< 500
Middle stream at Hankou (Wuhan conurbation), Hubei			< 200–5,000	400–500	200–300
Lower stream at Nanjing, Jiangsu			< 100–2,000	about 400	200
Huanghe (Yellow River)	5,464	1.6×10^9			
Upper stream at Lanzhou, Gansu			< 90–28,000	about 4,000	100–190
Middle stream at Zhengzhou, Henan			< 340–184,000	17,000–20,000	1,700–13,000
Lower stream at Jinan, Shandong			< 340–136,000	9,000	< 1,000
Zhujiang (Pearl River)	2,214	88.74 million			
Lower Xijiang (West River) at Wuzhou		82.4 million	4,990	490	
Middle Dongjiang (East River) at Longchuan		1.8 million	0.2–10,100	20–140	1–30
Lower Dongjiang at Boluo		2.9 million	0.4–5,900	30–190	4–40
Hanjiang (Han River)	ca. 360			(NTU)	
Delta branch at Shantou Town			10–800		
Delta branch at Chenghai Town			25–2,800	100–300	25–100

*The data on total annual silt discharge, suspended solids and turbidity were obtained from Prof. Qian Chong Zhan (Changjiang and Huanghe), Mr Liang Zhiyong (Xijiang), Dr Jin Changxing (Dongjiang), Prof. Du Yi-Ming and Mr Huan Ren Ning (Hanjiang).

1,500 kg/m³ (Lin & Li 1986, p. 13). About 400 million tons of sand and silt of the Huanghe settle in the lower course before reaching the sea. Therefore the riverbed in Shandong is often 3–5 m higher, in some places even 12 m higher, than the ground level outside the confining levees. Industrial pollution is very low in this ‘suspended river’. Factories release their wastewater into small rivers

running parallel to the Huanghe (Ch. Xiu, personal communication 1996).

Zhujiang and Hanjiang

In South China, the rivers have their outlet in the South China Sea. The river system of the Zhujiang (pearl river)

has a low sediment load and an annual run-off of 326 milliard m³. It is made up of the Xijiang (West-), the Beijiang (North-) and the Dongjiang (East River) which are in their lower reaches criss-crossed by a multitude of waterways and canals (Weng & Dong 1992, p. 22). The name 'Pearl River' refers to a former sandbank with pearl oysters in the middle of the Zhujiang proper, the main waterway at Canton (Guangzhou, China (Buchreihe 1984, p. 116)). The Xijiang, which has its origin in eastern Yunnan, provides 77–78% of the run-off and the highest annual silt discharge of the system (Table 1). The water quality of the outlets of the *Zhujiang* system is affected by semi-diurnal mixing with tidal currents. During the dry season salt water can penetrate more than 100 km inland. Water salinity promotes deposition of silt by flocculation of suspended matter (Chen & Che 1992, p. 108). Waterworks benefit from this natural clarification.⁴ In 1995, raw water from the Modaomen, the main outlet of the Xijiang, had turbidities of 2–27 NTU (suspended solids: 0.1–33.7 mg/l). Pollution is also low (Shuca, Macao, personal communication 1996) because the Modaomen has a strong run-off and is coming from an area with a few factories. The highest pollution with industrial wastewaters and domestic sewage is found in the outlet connected to the Guangzhou waterway. Since it has a weak run-off, the river water is driven back and forth with the tides and the discharge of polluted water to the sea is impaired (Wu 1992, p. 164). The second longest river in Guangdong is the Hanjiang (Han River), named after a scholar who praised its beauty (Y. M. Du, personal communication 1992).⁵ Its origin is in Fujian and its delta is between Shantou and Chenghai in eastern Guangdong. In Chenghai County, drastic rises in turbidity to 2,000–3,000 NTU (Table 1) occur five to eight times a year after heavy rains between April and October and last about 5 days (R. N. Huan, personal communication 1992).

IMPACT OF VEGETATION COVER AND RAINFALL ON RIVER SEDIMENTS

The gradual disappearance of forests due to population growth has exacerbated soil erosion. The forest cover in

the Huanghe basin was, according to historical records, once as much as 53%. In 1986, it was 10% in the mid and downstream sections and 0.4% in the upper reaches (Ding 1992, p. 35), although soil and water conservation programmes had started after 1949 (Lin & Li 1986, p. 15). Guangdong was also covered by evergreen rainforest. Primeval pine forest was felled to provide farmland and fuel for the production of iron and steel. In 1975, the forest cover was still 52%. At present, it amounts to 13.3% in forest areas and only to 9% in semi-forest areas. One of the most eroded areas is Wuhua County in the upstream of the Hanjiang, which has a population density of 300 per km². In spite of laws on forest and soil conservation, erosion is continuously increasing. Farmers try to get as much profit as possible from the limited lands and still cut the ferns under the remaining trees for domestic fuel (Jin & Zang 1994, p. 154; Jin 1994, p. 54). Weathering of granitic bedrock to red soil is accelerated in the subtropical climate by strong solar radiation on bare soil (surface temperatures >58°C), diurnal temperature ranges up to 25°C and high precipitation. The heavy summer rains are responsible for 80% of the annual erosion. About 30% of them are typhoon rains with great denudating force resulting in benggangs (slope disintegrations) and disastrous landslides. In June and July rain events are observed every two days. If the soil moisture has become high and the infiltration rate low, rainfalls of about 50 mm are sufficient to induce the removal of large amounts of soil particles (Jin & Zang 1994, p. 149; Jin 1994, p. 49).

According to my assessments of available data from the stations at Longchuan and Boluo (1960 (start of gauging)–1985) the water of the middle and lower reaches of the Dongjiang is almost clear during the dry season (Table 1). Short-term rise of the sediments to >100 p.p.m. is rare (Table 2). During the wet season (April to September), long periods of sediment increase are mainly found in June and July. Early heavy rains induce similar changes already in February and March. In the lower Dongjiang at Boluo the range of annual sediment load was 0.33–4.84 million tons per year from 1960 to 1969, 1.61–4.56 from 1970 to 1979 and 2.07–5.45 million tons per year from 1980 to 1985. Tributaries of the Hanjiang were probably more affected by the environmental deteriorations of recent decades.

Table 2 | Sediment fluctuations in the middle and lower reaches of the *Dongjiang* at *Longchuan* (L) and *Boluo* (B) in years with low, medium and high rainfall*

Year	Rainfall		Annual sediment load (million tons/yr)	Number of days with substantial increases of sediment		
	Annual (mm)	Maximum of one week		Dry season >100 ppm	Wet season	
					>100 ppm	>1,000 ppm
1963	970	135				
L			0.25	not yet daily		
B			0.33	records		
1965	1,883	277				
L			1.27	4	26	0
B			1.84	3	48	1
1966	2,262	651				
L			2.52	2	32	6
B			4.54	0	69	12

*Copies of the sedimentological records from Longchuan and Boluo and data on rainfall measured at Heyuan (located between the two stations) were provided by Dr Jin Changxing.

TRADITIONAL CLARIFICATION OF RIVER WATER

Huanghe

The earliest known Chinese clarifier is glue from animal hides (collection of recipes by Huai Nan, 2nd century AD, P. Xiao, personal communication 1991). The famous alchemist Ko Hung (Baopuzi Jiadun, 4th Century) refers in this context to the Yellow River:

One inch of glue is useless against the turbidity of the whole Huanghe

(P. Xiao and G. Chen, personal communication 1991)

The monk Zan Ning related how the clarification was carried out:

The people living near the river use river water. If one smears the inside of a container with E-glue [and then fills it with water], it soon becomes clear. This glue is from the district Dong-E. There is a well. Water from the well is boiled with cow hide to produce the glue

(Wulei xiangkan zhi (*On the mutual responses of things according to their categories* [980])); G. Chen, personal communication 1991)

Another type of clarifying glue was ejiao made from donkey hide (same source, J. Pan, personal communication 1991). Glue from bones or hides contains denatured collagen, a protein that acts mainly as adsorbent (Table 3). The degree of viscosity and the molecular mass are responsible for differences in efficiency (Audsley 1965, p. 18). In Graeco-Roman times, it was used for fining (clarifying) wine (Lehmann 1980, p. 32). In the 20th century, Swedish iron ore mines (Öhman 1954, p. 102) and South African uranium mines (Audsley 1965, p. 18) applied glue as a filter aid for wastewater. Chinese waterworks used it as a coagulant aid for drinking water before the introduction of activated silica and polyacrylamides (Ch. Zh. Qian, personal communication 1993).

At the end of the 17th century the missionary Navarette was sailing on the Huanghe to the Royal Court.

Table 3 | Overview on local clarifiers of animal and plant origin used in different parts of China

Clarifier	Active substance	Efficiency	Health risk	Recorded sites of treatment
Clarification mainly due to Adsorption of suspended matter				
Glue from hides	denatured collagen	coagulant aid	probably none	Huanghe
Mucilaginous plant materials				
<i>Anamiirta paniculata</i> (fruits or seeds)*			presence of picrotoxin	Zhujiang (Canton)
<i>Aloe vera</i> (sap of leaves)	Glyco-aloe-modinanthrone + tannin	can act as coagulant aid	probably none	Hanjiang
<i>Opuntia dilenii</i> (sap of cladodes)	carbohydrate polymers	<i>Opuntia</i> extracts: coagulant aids	probably none	Changjiang and tributaries (Sichuan)
<i>Cyrtomium falcatum</i> (crushed roots)			not known	tributaries of Hanjiang
Clarification by weak Coagulants				
<i>Diospyros kaki</i> (sap of fruits)	tannins	clarifying effect confirmed	presence of tannins?	demonstration in S. China
<i>Cucurbita moschata</i> (crushed leaves)		clarifying effect confirmed by experiment	not known	trials in different parts of China
<i>Phaseolus mungo</i> seeds		<i>Ph. vulgaris</i> tried out as coagulant in the Sudan	not known	site not recorded
Clarification by primary Coagulants				
<i>Prunus armeniaca</i> (kernels)	probably a polymer	trad. coagulant also in Egypt	presence of amygdaline	Changjiang and tributaries (Jiangxi, Sichuan)
<i>Prunus persica</i> (kernels)	probably a polymer	trad. coagulant also in S. Africa and Bolivia	not known	site not recorded

*Material probably imported for use as fishberries.

Since he was accustomed to take along provisions of ground water for such trips, he was very surprised that boat people prepared clear, well-tasting water by shaking river water with ‘a little alum’ (Baker 1948, p. 302). In 1643, ‘white alum’,⁶ realgar and gypsum were also mentioned for the first time as clarifying materials in a Chinese source (Hang Yishi: Wuli xiaozhi [*Small Encyclopaedia of the Principles of Things*], chapter 2, J. Pan, personal communication 1991). Realgar⁷ (arsenic disulfide: As_2S_2) is not known as a coagulant in other countries. Gypsum ($CaSO_4$) was also a traditional clarifier of the Australian aborigines around Cooper’s Creek (Jahn 1981, p. 69). Its destabilization of water colloids is due to the divalent Ca ions.

Changjiang

When the government official, poet and alchemist Lu Yu was sailing on the Changjiang to Sichuan in 1170, he found that turbid river water of the middle reaches in Jiangxi (close to lake Bojang) was ‘settled overnight’ with xing ren (G. Chen and P. Xiao, personal communication 1991). These are apricot (*Prunus armeniaca*) kernels, not almonds as translated by Chang & Smythe (1981, p. 98).⁸ Apricot and peach (*Prunus persica*) kernels were also mentioned as clarifiers by Li Shi-chen (Bencao gang mu vol. 2, 1596) and by Hang Yizhi (Wuli xiaozhi, 1643) who referred in addition to small red beans (J. Pan, personal communication 1991).⁹ Elder people in Sichuan still remember that turbid waters of the Changjiang and its tributaries were treated with xing ren (Song, personal communication 1995). Bitter-tasting apricot kernels contain 3–4% amygdalin, a glycoside that yields hydrocyanic acid (HCN). Serious intoxications were observed after a person had eaten 20 apricot kernels (Watt & Breyer-Brandwijk 1962, p. 892). People in Sichuan, who have no access to public water supplies, now clarify with the sap of xian ren zhang (*Opuntia dilenii*), a cactus from Latin America, which is now also grown in China. Others use plain sedimentation or alum (Song, personal communication 1995). These two household treatments are also still carried out in Hubei, although very poor farmers cannot afford to use alum (X. S. Ma, personal communication 1992).

Rivers in Guangdong

The already-mentioned Spanish missionary Navarette also came to South China where he looked at the drinking water of Tan-kia, Canton’s ancient houseboat quarter on the Zhujiang:

In Canton I learned another easier and wholesomer cure for it [turbid water], and it is only putting some very small grains which make fish drunk (and in Spanish are called coca) into a jar, and the water will become very clear in a very short time
(Baker 1948, p. 302)

Coca are the dried fruits or seeds of the climbing plant *Anamirta paniculata* (synonyms: *Cocculus suberosus*, *Cocculus indicus*; family *Menispermaceae*). In the past, some Europeans also stupefied fish with these ‘fishberries’ which contain the highly toxic alkaloid picrotoxin.¹⁰ Their use as a clarifier is so far not known from other countries. Extracts of the leaves of a related species, *Cocculus villosus*, syn. *C. hirsutus*, form in water a ‘mucilage’ or ‘jelly’ used in Indian native medicine (Nadkarni 1976, p. 362; Chopra *et al.* 1956, p. 72). The same mucilaginous extract has been also used as a coagulant for milk in India (Joret 1976, p. 352). In villages of Chenghai County, Hanjiang water was clarified up to 1950 with the mucilaginous sap of the leaves of lu hui (*Aloe vera*), now only used as a shampoo and to treat infected wounds and diarrhoea (Ch. X. Li, personal communication 1992). The clarifying effect might be due to glyco-aloe-modinanthrone, a polymer on carbohydrate basis, and to the tannin content of aloe resin. A report by Hespanhol & Selleck (1975) showed that an extract of dry leaves of *Aloe vera* compares as a low-cost coagulant aid with the mucilaginous sap of any species of *Opuntia* cactus (traditional clarifiers in Peru, Chile and parts of Central America). Before 1950, villagers in Northern Guangdong also clarified their water with crushed *Rhizoma cyrtomii* as a surgeon from Shantou University had seen in his home area (B. Chen, personal communication 1993). This root of the fern *Cyrtomium falcatum* (synonym: *Aspidium falcatum*; family: *Polypodiaceae*) is used in Chinese and Indian native medicine as a vermifuge (Wong 1978, p. 211; Chopra *et al.* 1956, p. 89). The forester Huang Shi-Mong from the University of Haikou, who accompanied me in Hainan, witnessed in 1980 in a village market at the

border between Guangdong and Guangxi (Xu Wen County) how a vendor showed many peasants his ‘medicine’ to purify ‘dirty water’:

Two tea mugs with clear and turbid water were placed in front of him. He took a shi [Diospyros kaki, family: Ebenaceae] fruit from his basket and cut it. Shortly after adding a small amount of sap, the turbid water became clear. The sap also removed the yellow colour of Chinese ink, which had been dissolved in water.

Kaki fruits are eaten in Southern China, but the tree is not cultivated everywhere. Since they are rich in tannins, the juice might be compared with ‘parting juices’ from pears, quinces, sloes and the fruits of sorbs and medlars which have been used in Europe to improve the clarification of apple juice with gelatine by removing positively charged impurities with their negatively charged tannin particles (Lehmann 1980, p. 38). The Chinese liberation army was very much interested in efficient water treatments for guerrilla fighters in remote areas. The most promising plant clarifiers recommended for this purpose were crushed leaves of *Cucurbita moschata* or other pumpkins grown in peasant gardens (S. M. Huang, personal communication 1992). Nan gua (southern gourds) are widely used as vegetables and in dietotherapy (Yang & Walters 1992, p. 350). After my return from China I could confirm the clarifying properties of the juice of kaki fruits and crushed leaves of the common pumpkin (*Cucurbita maxima*) by adding them by hand stirring to water with a turbidity of about 100 NTU. However, 30–60 minutes later, the treated water turned yellowish or green respectively and had acquired a ‘plant taste’.

The laboratories of South China University of Technology and Public Health Authorities in Guangdong did not have in 1992 equipment for studies on water coagulation. Simple determinations of the optimum dose of a coagulant can be also made by ‘village jar tests’ (Jahn 1988a, p. 45). Some of the Chinese colleagues who were keen to see a demonstration joined me in synchronized hand stirring. At this occasion they could compare fast clarification by a suspension of *Moringa oleifera*¹¹ seeds and by an alum solution. There was not yet awareness that residual aluminium in drinking water must be controlled and that alum-containing coagulants of low quality may add harmful trace elements to the water (cf. Jahn 1999,

p. 425, Table 3). In Guangdong, typical methods for traditional alum use are: to rub a lump against the wall of a water bowl and to stir turbid water with a perforated bamboo stick filled with crushed alum (Jahn 1999, p. 426). If highly turbid water is treated with overdoses of alum, the high sulphate concentration in the drinking water can cause gastrointestinal discomfort. I do not know whether rural women in China also have felt pain of this type and then feared abortion, as happened to women in the Northern Sudan (Jahn 1981, p. 92).

WATERWORKS OPERATION ALONG THE GREAT RIVERS

The first Chinese waterworks were established in trade centres where foreigners had settled such as Shanghai (1883), Guangzhou (1905), Wuhan (1906), Shantou (1907) (Chinese Water Supply Association 1989, pp. 38, 56, 102, 109). In Shanghai, British consultants introduced alum as coagulant for water of the Huangpu, a tributary of the lower Changjiang (Ch. Zh. Qian, personal communication 1993).

In riverain Chinese towns, the ‘Water Purification Factories’ of the ‘Running Water Companies’ usually supply water from different sources. The first Municipal Plant of Jinan, for example, was built in 1936 for chlorination of ground water. River water has been treated since 1987 for factories and workmen. In 1995 urgent efforts were made to increase the intake of Huanghe water to 60–70% because the aquifers had to be refilled (Ch. Xiu, personal communication 1996). Developments were similar in Zhengzhou (Y. Wang, personal communication 1996). In Jinan, clarification starts with pre-sedimentation in large basins (capacity: 18,000 m³, diameter: 100 m). After that the maximum doses of polyferroaluminium sulphate are only 60–80 mg/l. Coagulant aids are polyacrylamides. The great amounts of settled sand and mud are used for the river levees and the manufacture of bricks. In very cold winters, the Huanghe is frozen at the surface. This ice formation can cause great damage to the sedimentation basins resulting in shortage of purified water (Ch. Xiu, personal communication 1996). Since 1981, Chenghai

County has a rural plant for the treatment of Hanjiang water (40–60 litres daily for 50,000 consumers) in Lian shia. Peasants who breed ducks and therefore live in houseboats cannot benefit from this supply. They have to consume the river water as it is or use household treatments. Before 1990 the coagulant was alum (recrystallized potassium aluminium sulphate) from a mine in Zhejiang (Fujian). Now, polyferroaluminium-chloride of local production is used with standard doses of 5 mg/l (winter) and 8 mg/l (summer). Chlorination is not applied. The waterworks of Chenghai Town (capacity 20,000 t/d) also operate with standard doses. They cannot afford equipment and personnel to monitor water coagulation to the actual turbidity fluctuations and for regular chemical and bacteriological control of finished water. Chemicals for disinfection are not always available. According to health reports 'water-related diseases are rare because the main beverage is tea prepared with boiling water' (R. N. Huan, personal communication 1992). The Han Chinese only drink tea or spiced water made with boiled water even if they gave up other old religious (mainly Buddhist) traditions. They also care much for clear water (Y. M. Du, personal communication 1992). On the other hand, animists such as the Li and Miao in Hainan or other parts of South China, also drink apart from tea any available cool water, which they do not boil before consumption. If they cannot get spring or well water, they also take turbid surface water (Sh. M. Huang, personal communication 1992).

The drinking water supplies for the territories of Hong Kong and Macao were originally based on ground water and harvested rainwater. For a few decades additional river water had to be bought from the China. The waterworks in Hong Kong get water from the Shenzhen, a tributary of the Dongjiang (Tso, personal communication 1993), the Chinese–French Company in Macao from the Modaomen. From 1986 to 1989 a 16 km long common raw water supply system for Zhuhai Special Economic Zone in the China and Macao was constructed. During periods of high salinity in the Modaomen, safe raw water is obtained by monitoring the opening and closing of the two intake gates situated at different distances from the sea, and by dilution with fresh surface water from reservoirs (Shucaï, personal communication 1996). The

coagulant in Hong Kong is alum, in Macao poly-aluminiumchloride¹² with polyacrylamide as coagulant aid. Both companies provide water of European quality standards, and ensure in particular that the residual aluminium in their drinking water is less than 50 µg/l (Packham & Ratnayaka 1992, p. 38). The waterworks in Hong Kong and Macao have research programmes of regional interest. There are in addition training courses sponsored from abroad. In Macao they are also open to Africans from former Portuguese colonies who have a basic knowledge of Mandarin.

DISCUSSION

The data on traditional water clarification presented in this paper could certainly be supplemented by further search in Chinese archives and extensive fieldwork in communities of the Han-Chinese and minorities. Sediment load of river water, climate and easy access to materials had a great impact on treatment possibilities and resulting improvements of physico-chemical and microbiological water quality. Adsorptive gelatinous or mucilaginous materials (glue, cactus and aloe sap) or plain sedimentation can yield substantial improvement to waters with high sediment load (Huanghe, Changjiang in Sichuan, Hanjiang after typhoon rains) but they cannot achieve fast removal of colloidal dispersed particles. Although a turbidity of 3,500 FTU of Blue Nile water had dropped to 130 FTU after plain sedimentation for 24 hours, the water was not yet clear after 3 weeks (13 FTU (Jahn & Omer 1984, p. 153)). Apricot kernels, the most efficient Chinese plant clarifier, act as a primary coagulant. There is evidence that they were substitutes for the Indian 'clearing nuts' (*Strychnos potatorum* seeds), which are not available in China, and that later cultural exchanges between Muslims from China and Egypt were responsible for the use of apricot and almond kernels for clarification of turbid Nile water, recorded since the 16th century (Jahn 1994, pp. 50, 53). In the Changjiang valley the nan-xing (apricot of the South) is grown extensively whereas the bei-xing (apricot of the North) is not common in the cool basin of the Huanghe (Leung 1985, p. 138).

Plant clarifiers are probably also not in use in northern China because the speed of physico-chemical processes is much decreased at low water temperatures. In winter even the voluminous flocs of aluminiumhydroxide settle very slowly without a coagulant aid. The settling of the fine flocs produced by a plant coagulant, such as *Moringa oleifera* seeds, is still more impaired with decrease of water temperature (cf. Jahn 1986, p. 87). Several plant clarifiers from sub-tropical areas of China belong to the same plant families used in Africa or Latin America or contain substances that have been already utilised for the production of commercial coagulant aids. It is surprising, however, that pulses, widely used in the Nile valley, are almost unknown in China. In Egypt and the Sudan, the most efficient type of bean are broad beans (*Vicia faba*). It also seems that no traditional Chinese plant clarifier belongs to the *Capparales* (*Capparidaceae*, *Moringaceae*), which are very common in Africa (Jahn 1988b, 174 ff.) (Tables 1 and 2). Since water clarification started as a technology of the poor classes, the natural clarifiers had to be local farm products or they were needed for work, such as the Indian fishberries in Canton.

The Chinese records on the traditional use of alum for water clarification are the earliest worldwide. Alum could become the dominating traditional clarifier because China has rich resources of alunite and other aluminium minerals in several provinces. Yet, alum was also applied with random doses and without proper agitation input. Optimum conditions for water coagulation could only be found by scientific research. French and British chemists and engineers achieved the global dissemination of alum as a coagulant for public water supplies in the 19th century (Jahn 1999, pp. 424, 428). We have to assume that pastoral tribes tried out animal glues, fishermen seeds that paralyse fish, rural women and healers edible and medicinal plants. Alum was probably detected by artisans. Alum-based 'clarifier stones' were perhaps also found by travellers through the wilderness like in Africa (Jahn 1999, p. 424). Muslims, Christians or Animists had no reason to object to a clarifier of animal origin. Buddhists with strong belief in protecting animal life could not accept animal glue and used instead mucilaginous saps or coagulants from plants or clarifiers of mineral origin.

CONCLUSIONS

Sediment load and contamination of Chinese river waters have much increased during the 20th century. Despite old preferences of wealthy and educated people for well and spring water, the exploitation of river water for urban and rural supplies has increased and will continue to increase. Special Economic Zones such as Shantou (Hanjung delta) or Zhuhai (Zhuijiang delta) now consider it a priority to spend money on modern equipment and better training facilities for the academic and technical staff of their water purification factories which have also to deal with river water. However, there are remote, poor Counties with a mainly rural population which do not have enough public waterworks. Special strategies are also needed after sudden drastic deterioration of drinking water due to floods and land slides. If household treatments at village level are monitored by the local primary school teachers, it is possible to apply both alum and natural coagulants by semi-quantitative methods. Thereby the quality of drinking water from rivers can be not only improved as long as the raw water is highly turbid but also during seasons when turbidity has dropped to medium and low degrees (Jahn 1986, chapter 6; 1988a, 45 ff.). Successful clarification results also in a reduction of indicator bacteria by up to 98–99% because the microbes are settled together with the clay fraction. The efficiency of clarifiers that act mainly as adsorbents of suspended matter can be improved in a similar manner by dose recommendations based on trials with the raw water. Overdoses of clarifiers not only spoil material and efforts, they can cause health risks, unpleasant taste of the treated water and growth of microbes due to increase of organic material. Fortunately there are already non-governmental organisations (NGOs) that take pride in Chinese traditions and promote modernized practical solutions. In Sichuan, for example, an NGO for appropriate science and technology is also interested in low-cost treatments of river water (Song, personal communication 1995). Self-help programmes for poor and remote districts should be very beneficial for several provinces. The untrained rural people need advice on most suitable materials and methods of purification. Water technicians as well as teachers and students from colleges of agroforestry, pharmacology and teachers'

training could help them. Minorities who drink unboiled water should be provided with special instructions about sand filtration or solar disinfection for use after clarification.

ACKNOWLEDGEMENTS

The author thanks: Professor Qian Chong Zhan (North China Municipal Engineering Design Institute, Tianjin) and Dr Jin Changxin (Dept. of Geomorphology, Academia Sinica, Beijing) for their great efforts in providing difficult data on river sediments; Mr Benno Dröge (Global Runoff Data Centre, Bundesanstalt für Gewässerkunde, Koblenz) for help with literature and introduction to Chinese colleagues of the Sino-German research project. Valuable information, literature and references were also obtained from Dr Shuchail Zhu (Laboratory and Research Centre) and the French manager, Mr Paul Ledoigt of the Macao Water Supply Company, Mr. Pan Jixing (Institute for the History of Sciences, Academia Sinica, Beijing), Mr Chen Guangzu and Mr Xiao Pan (Institute of History and Philology, Academia Sinica Taipei, Chinese Taiwan) and Mr Liang Zhiyong (Institute of Water Resources and Hydropower Research, Beijing). Dr Chen Bingxie (Medical College, Shantou University), Mr Song Yuhua (Chengdu Xinguang Development Corporation for Appropriate Science and Technology, Sichuan), Mr Tso Wing-Shui (Water Supplies Department, Hong Kong), Dr Denise Baxter (Brewing Research Foundation International, Nutfield, England) and my postgraduate students from the course on water management in the tropics (University of Applied Sciences, Suderburg), Mr Xiu Chunhai and Mr Wang Yu (Waterworks at Huanghe in Jinan and Zhengzhou) and Mr Ma Xin-Sen from Hubei kindly answered my questions. I also sincerely thank Professor Du Yi-Ming (retired from the Department of Civil Engineering, Technical University, Guangzhou) who arranged for technical visits in Guangdong and Fujian and accompanied me; to Mr Li Chang Xin (Shantou Sanitary Agency), Mr Huan Ren Ning (Public Health Office, Waterworks, Chenghai County) and to Mr Huang Shi Mong (Center for Biology, Haikou University, Hainan) for

valuable explanations and discussions during my field studies.

REFERENCES

- Audsley, A. 1965 Flocculation of suspensions & of solids with organic polymers – a literature survey. *Mineral Processing Information Note No.5*, Warren Spring Laboratory, Stevenage, UK.
- Baker, M. N. 1948 *The Quest for Pure Water*. American Waterworks Association, New York.
- Bretschneider, E. 1895 *Botanicon Sinicon – Notes on Chinese botany from native and Western Sources*, part 3. Kelly & Walsh, Shanghai.
- Chang, Chun-Shu & Smythe, J. 1981 *South China in the Twelfth Century – A Translation of Lu Yu's Travel Diaries July 3–December 6 1170*. Chinese University Press, Hong Kong.
- Chen, Shangqun & Che' Wencai 1992 Analysis of the hydrological and sedimentary characteristics of the water zone around Macao. In *Proceedings of the International Conference on the Pearl River Estuary, ICPRESAM, Macao*, pp. 97–109.
- China Buchreihe (ed.) 1984 *Geographie*. Verlag für fremdsprachige Literatur. Beijing.
- Chinese Water Supply Association 1989 *Water Supply in Cities of China*. Beijing.
- Chopra, R. N., Nayar, S. L. & Chopra, I. C. 1956 *Glossary of Indian Medicinal Plants*. Council of Scientific and Industrial Research, New Delhi.
- Ding, Zhao 1992 Forest cover. *World Water and Environmental Engineer*, October, 33–37.
- Eberhard, W. 1987 *Lexikon chinesischer Symbole – Die Bildsprache der Chinesen*. Diederichs Gelbe Reihe, Köln.
- Franke, Otto 1910 Zur Frage der Einführung des Buddhismus in China. *Mitteilungen des Seminars für Orientalische Sprachen* 13, 295–305.
- Hesphanhol, I. & Selleck, R. E. 1975 The role of polyelectrolytes in flocculation kinetics. *Berkeley SERL Report no. 75*.
- Jahn, S. Al Azharia 1977 Traditional methods of water purification in the riverain Sudan in relation to geographic and socio-economic conditions. *Erdkunde (Bonn)* 31, 120–129.
- Jahn, S. Al Azharia 1981 Traditional water purification in tropical developing countries – existing methods and potential application (manual). *Dtsch. Ges. techn. Zusammenarb.* (GTZ), Ser. Publ. No. 117.
- Jahn, S. Al Azharia 1986 Proper use of African natural coagulants for rural water supplies. Research in the Sudan and a guide for new projects (manual). *Dtsch. Ges. techn. Zusammenarb.* (GTZ), Ser. Publ. No. 191.
- Jahn, S. Al Azharia 1988a Using *Moringa* seeds as coagulants in developing countries. *J. Am. Wat. Wks Ass.* 80, 43–50.
- Jahn, S. Al Azharia 1988b Chemotaxonomy of flocculating plant materials and their application for rural water purification in developing countries. *Symb. Bot. Ups.* 28 (3), 171–185.

- Jahn, S. Al Azharia 1994 On the history of water coagulation – transfer of ancient Hindu practices to the valleys of the Yangtze River and the Nile. *ASIEN (Hamburg)*, No.50, 45–57.
- Jahn, S. Al Azharia 1996 On the introduction of a tropical multipurpose tree to China – traditional and potential utilisation of *Moringa oleifera* Lam. *Senckenbergiana biologica* **75**, 243–254.
- Jahn, S. Al Azharia 1999 From clarifying pearls and gems to water coagulation with alum. History, surviving practices and technical assessment. *Anthropos* **94**, 419–430.
- Jahn, S. Al Azharia & Omer, El Fadil 1984 Water quality fluctuations in the Blue and the White Nile and the Green-Belt-Irrigation Canal south of Khartoum. *Water Quality Bulletin* **9**, 149–155.
- Jin, Chang-Xing 1994 The development of benggang in Guangdong Province, South China. *Int. J. Sediment Res.* (UNESCO and IRTCES, Beijing) **9** (3), 46–56.
- Jin, Chang-Xing & Zang Guohua 1994 An experimental study on sheet erosion in granitic region of Wuhua County, Guangdong Province. *J. Chinese Geog.* **4** (3/4), 148–158.
- Joret, C. 1976 [1st edn Paris 1897–1904] *Les plantes dans l'antiquité et au moyen age. Histoire, usages et symbolisme*. Slatkine, Geneva.
- Laufer, B. 1967 [1st edn 1919] *Sino-Iranica, Chinese Contributions to the History of Civilization in Ancient Iran*. Reprinted by Ch'eng-Wen Publishing Company, Taipei.
- Lehmann, H. 1980 *Fruchtsaftklärung*. VEB Fachbuchverlag, Leipzig.
- Leung, A. Y. 1985 *Chinesische Heilkräuter* [German translation of 'Chinese Herbal Remedies']. Diederichs Gelbe Reihe, Köln.
- Lin, Bingnan & Li, Guifen 1986 The Changjiang and the Huanghe, two leading rivers of China. IRTCES (International Research and Training Center on Erosion and Sedimentation, Beijing) Series of Publications, Circular No. 1.
- Nadkarni, K. M. 1976 [1st edn 1908] *Indian Materia Medica*, vol. 1 Bombay.
- Nielsen, H. 1980 *Eksotiske laegeplanter og trolddomsurter*. Politikens Forlag, Copenhagen, Denmark.
- Öhman, V. 1954 Rening av avfallsvatten från anrikningsverk med limflockning. *Jernkontorets Annaler (Sweden)* **138** (2), 97–112.
- Packham, R. F. & Ratnayaka, D. D. 1992 Water clarification with aluminium coagulants in the UK. *Wat. Supply* **10**, 35–47.
- Rätsch, C. & Guhr, A. 1989 *Lexikon der Zaubersteine aus ethnologischer Sicht*. Akademische Druck- und Verlagsanstalt, Graz, Austria.
- Shandong Environmental Health Station and Institute of Health, Academy of Medical Sciences & Ministry of Public Health, Beijing 1982 The Yellow River. *Wat. Qual. Bull.* **7**, 176–177, 192.
- Wan, Zhaohui & Gao, Jing 1994 The role played by wash load deposition in the formation of different river patterns. *Int. J. Sediment Res.* (UNESCO & IRTCES, Beijing) **9**(3), 156–165.
- Watt, J. M. & Breyer-Brandwijk, M. G. 1962 *Medicinal and poisonous plants of Southern and Eastern Africa*. Edinburgh and London.
- Weng, Yimeng & Dong, Zhaoying 1992 Improvement and development of Pearl River estuary. In *Proceedings of the International Conference on the Pearl River Estuary, ICPRESAM, Macao*, pp. 19–31.
- Wong, Ming 1978 *Handbuch der chinesischen Pflanzenheilkunde* (translated from the French original by Anette Lallemand). Hermann Bauer Verlag, Freiburg i. Br.
- Wu, Jianzhou 1992 Trend analysis of oxygen consumed organic substances in the Pearl River estuary. In *Proceedings of the International Conference on the Pearl River Estuary, ICPRESAM, Macao*, pp. 161–169.
- Yang, Si-Lin & Walters, T. W. 1992 Ethnobotany and the economic role of the Cucurbitaceae of China. *Econom. Bot.* **46**, 349–367.
- Zuo, Dakang & Xing, Yan (Institute of Geography, Chinese Academy of Sciences (editors)) 1992 *The Natural Features of China*. China Pictorial Publishing House, Beijing.

NOTES

¹In China the name Yangtze or Yangzi River refers only to the last section of the lower course between the district Yangzhou and the mouth of the river (China Buchreihe 1984, p. 112).

²In the China Statistical Yearbook 1998 published by the State Statistical Bureau of the People's Republic of China, the run-off data are now recorded as 661 and 9,513 (100 million m³) which is equivalent to 66.1 and 951.3 × 10⁹ m³.

³NTU (nephelometric turbidity units) and FTU (formazin turbidity units) are synonyms. Authors usually report their results according to the unit used by the manufacturer of their turbidimeter.

⁴The effect is due to the coagulating properties of Mg²⁺ and Ca²⁺ from sea water.

⁵The Confucian Han Yü (768–824) was banished by the emperor to the Hanjiang delta where the people of Swatow (Chaozhou) deified him and built a shrine in his memory (Franke 1910, p. 297). A different Han River is the longest tributary of the Changjiang.

⁶West-Asiatic variety imported until the late Middle Ages (Laufer 1967, p. 475) as a high-quality mordant, for bronzing, paper making, etc. (Jahn 1999, p. 424).

⁷Realgar is still in use in Sino-Tibetan native medicine as an aphrodisiac and in potions to achieve longevity. Intoxications have been reported after external and internal application (Rätsch & Guhr 1989, p. 134).

⁸The name xing ren has been translated incorrectly as ‘almonds’ by several European scientists and customs authorities because the kernels of both species are used for the extraction of ‘almond oil’. Scientific evaluation of coagulation with apricot kernels, which were later also used in the Nile valley, is not yet available (Jahn 1994, pp. 51, 55).

⁹A variety of *Phaseolus mungo* (cf. Bretschneider 1895 part III, p. 386). Beans of different species are common clarifiers for Nile water in Upper Egypt and the Sudan (Jahn 1981, p. 20).

¹⁰Some German brewers flavoured their beer with the cheaper, very bitter *Fructus cocculi* rather than with hop (Herbal by Tabernaemontanus, 1588, Baxter, personal communication 1993). In England this illegal bittering resulted, up to the 19th century, in fatal accidents after excessive beer consumption (Nielsen 1980, p. 83).

¹¹*Moringa oleifera*, a native of India, was introduced to South China through Macao, Vietnam and probably also

Thailand, Burma, Cambodia and Laos. In towns it was used as an ornamental, in rural areas as a vegetable tree, medicinal plant and a support for growing betel vines. During my visit in 1992 new cultivation trials started in Raoping County (Guangdong, Jahn 1996, pp. 246, 251, Fig. 7, 252), although the seeds and leaves were then only commercially used for a new ‘Chinese health tea’ (Y. M. Du, personal communication 1996).

¹²A small factory in Zhangpu (Fujian), for example, supplies many treatment plants in Eastern Guangdong, but does not yet have facilities for current control of the product. Polymers from China bought by the waterworks in Macao are analysed there before use. If a brand has European quality standards regarding concentrations of harmful trace elements, it is also recommended for sale to foreign countries.