



Water Pollution and Human Health in China

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China's extraordinary economic growth, industrialization, and urbanization, coupled with inadequate investment in basic water supply and treatment infrastructure, have resulted in widespread water pollution. In China today approximately 700 million people—over half the population—consume drinking water contaminated with levels of animal and human excreta that exceed maximum permissible levels by as much as 86% in rural areas and 28% in urban areas. By the year 2000, the volume of wastewater produced could double from 1990 levels to almost 78 billion tons. These are alarming trends with potentially serious consequences for human health. This paper reviews and analyzes recent Chinese reports on public health and water resources to shed light on what recent trends imply for China's environmental risk transition. This paper has two major conclusions. First, the critical deficits in basic water supply and sewage treatment infrastructure have increased the risk of exposure to infectious and parasitic disease and to a growing volume of industrial chemicals, heavy metals, and algal toxins. Second, the lack of coordination between environmental and public health objectives, a complex and fragmented system to manage water resources, and the general treatment of water as a common property resource mean that the water quality and quantity problems observed as well as the health threats identified are likely to become more acute. *Key words:* China, health, pollution, water. *Environ Health Perspect* 107:251–256 (1999). [Online 5 March 1999] <http://ehpnet1.niehs.nih.gov/docs/1999/107p251-256wu/abstract.html>

Poised to become a superpower, China confronts some of the most serious environmental threats in the world. Water in China poses a triple threat: supply is scarce in the populous north, flooding endangers lives and land in the south, and growing municipal and industrial pollution jeopardizes regions throughout the country.

China has as much water overall as Canada, and has 100 times more people. China's per capita water reserves of 2,500 m³ are one-fourth the global average (1). Officially designated water pollution accidents, usually triggered by heavy rainfall, floods, or drought, often overwhelm the inadequate wastewater storage and treatment infrastructure. These events can force the release of industrial wastewater or sewage overflows and reduce the supply of fresh water available to dilute pollutants (2). As of 1996, only 5% of municipal wastewater and 17% of industrial discharge received any treatment before being discharged into lakes, rivers, irrigation ditches, or the coastal waters (3). A map of China's major rivers reveals that most of them do not meet Grade II requirements, which are the government standards for primary drinking water supplies, and some rivers are unsuitable even for agricultural purposes (Fig. 1; Table 1 describes the water quality grades in greater detail).

The degraded condition of much of China's surface water resources, together with the lack of coordination between protection of public health and management of water quality, pose serious threats to human health. This paper analyzes recent Chinese reports on water resources and health, with the understanding that the chronic health consequences that result from changes in environmental conditions only begin to appear in health and epidemiologic records after a decade or two (5). The water resources and public health literature in China implicate three principal threats to human health from water pollution and degraded water quality: 1) rapid and unregulated expansion of industrial activities; 2) growth of urban and suburban areas without adequate investments in water supply infrastructure; and 3) adoption of green revolution technologies together with a continued reliance on sewage irrigation. After examining the research on these recent developments, we present policy options under active discussion by national and regional authorities—discussions that are aimed at substantially reversing the historic degradation of China's water resources.

Rapid Industrialization

The transition from a command economy to a market economy has brought tremendous changes to China. The contribution of

state-owned enterprises to overall economic production is declining, while township-village enterprises (TVEs) and other parts of the private sector are playing a larger role. TVEs are the various enterprises established outside of urban areas with the majority of investment (>50%) from rural collective organizations or farmers. The economy's high growth rates—largely fueled by TVEs—coupled with structural shifts in the economy are exerting extraordinary pressure on natural resources, particularly water.

Along with this economic growth, China has experienced a slow and steady increase in the production of industrial wastewater. Between 1981 and 1995 the volume of wastewater increased 27.8%, an average annual increase of 1.65% (6). In recent years, official statistics indicate a drop in wastewater discharges from state-owned enterprises because of their shrinking production levels; however, this has been more than offset by the growth of TVEs. From their inception in 1958, TVEs have played an increasingly important role in all sectors of the economy. While the total TVE output was only 49.3 billion yuan in 1978, accounting for 7% of the country's total gross domestic product (GDP), this output increased to ¥6.9 trillion in 1995, accounting for 55.8% of the total industrial GDP—significantly higher than that of state-owned enterprises.

A subset of TVEs, township-village industrial enterprises (TVIEs), account for the majority of this phenomenal increase in industrial output. In 1994, the total output of TVIEs accounted for 42% of the total national industrial output, as compared to 23.8% in 1989; and accounted for 55.4% of the total rural GDP in 1994—a dramatic increase. In 1995, TVIEs discharged 5.9 billion tons of wastewater, 21% of the total discharged nationwide. As a result, although total wastewater discharge by

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TVIEs does not seem large, their contribution to the total share of pollutants is substantial. In 1989, the discharge densities for heavy metals, cyanide, and phenol in TVIEs were 2.2, 3.3, and 9 times greater, respectively, than those of industries located in urban areas. Among all TVIEs, three industries account for the largest discharges: paper and pulp mills (806 million tons of wastewater or 30.03%), chemical industries (159 million tons or 5.93%), and textile dyeing and staining plants (123 million tons or 4.57%) (7).

These national statistics are reflected in a 1989–1991 study (8) of 10 major polluting sectors of Chinese TVIEs in Beijing,

Liaoning, Jiangsu, Shandong, Guizhou, Guangdong, and Hubei. Organic matter, acids, alkalis, nitrogen, phosphate, phenols, cyanide, lead, cadmium, mercury, and bichromate were among the major water pollutants found in the bodies of water near rural residential areas and their drinking water systems. Monitoring results showed that all the major pollutants analyzed exceeded national standards for drinking water quality. Mercury concentrations were 45–700% in excess of the standard, whereas concentrations of lead were 3,600–5,216% greater than the standard. Table 2 lists China's national standards for drinking water quality.

In a number of studies, pollutants released by TVIEs have been linked to adverse health effects. In China overall, liver and stomach cancer deaths have doubled since the 1970s, and are now the leading causes of cancer mortality in rural China (9). China now has the highest liver cancer death rate in the world (9). When TVIEs in more polluted areas are examined, they show a general increase in cancer mortality. (Fig. 2). Figure 2 also demonstrates that cancer mortality in polluted areas has been steadily increasing over time. Although diet and alcohol consumption may play a role in the increased cancer rates, environmental factors are also relevant.

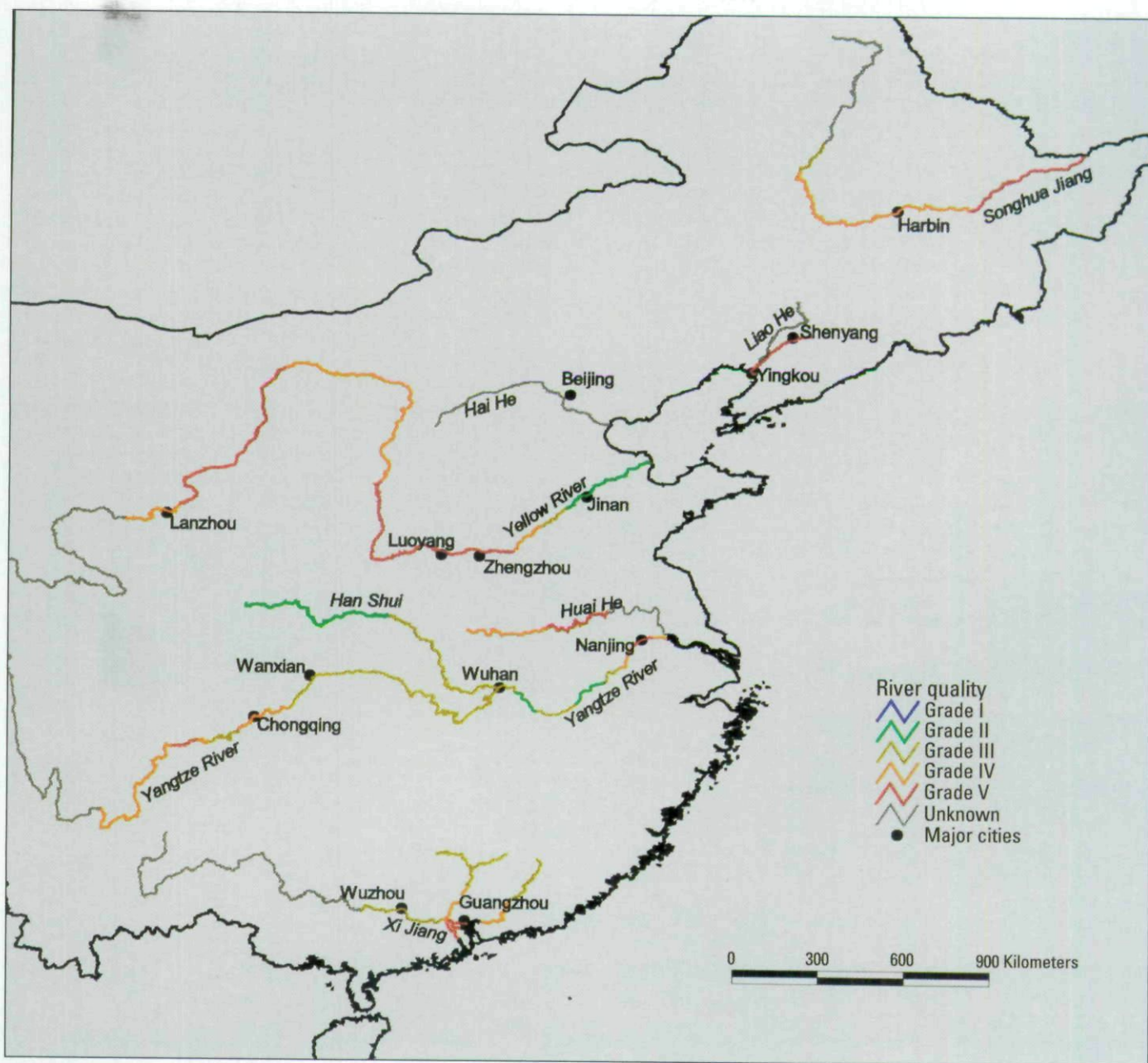


Figure 1. China's major rivers.

One illustration of the link between cancer and pollution in China comes from a 1987–1988 study of two villages, Xujia and Xizhou, where water supplies were polluted by petroleum industries (10). Deep groundwater, the source of village drinking water supplies, was heavily contaminated by hydrocarbons such as aliphatic and aromatic alkenes, phenols, aldehydes, ketones, acids, esters, etc., with concentrations of petroleum derivatives at 0.078–0.500 mg/l, volatile phenols at 0.001–0.003 mg/l, and sulfides at 0.059–0.451 mg/l (10). When compared to a control area, major findings included a >25% higher rate of overall cancer mortality from 1986 to 1988 and a >50% higher rate of cancers of the gastrointestinal tract during the same time period (10).

Urbanization

Polluted water resources are not only a problem in the rural areas surrounding TVIEs. Chinese cities have limited facilities or infrastructure to treat sewage or drinking water, which mostly comes from surface water of large rivers or lakes. More than 300 of China's 640 cities now face water shortages, with a total annual scarcity of nearly 6 billion m³. Most cities and communities simply discharge untreated wastewater and sewage produced by households and industries into surrounding surface waters, including rivers, lakes, and coastal areas (9). The increasing volume of human excreta as well as toxins and solid wastes from industries in urban areas is leading to a severe deterioration of water

quality. In fact, most urban water pollution is linked to organic loads entering water bodies (11).

A major problem for China is the inadequate treatment of municipal sewage. In 1996, more than 20 billion tons of urban sewage was discharged into rivers, lakes, or seas, with approximately 10% receiving any treatment by the 135 centralized sewage treatment plants that operated nationwide (12). Without proper disposal or treatment of sewage, most monitored river sections in urban areas (131 of 135) failed to meet designated water quality grades in a 1994 study (4). Table 1 lists the determining factors of each water quality grade.

Given the lack of wastewater treatment infrastructure, it is not surprising that low levels of sewage treatment have resulted in widespread contamination of drinking water supplies, and in turn resulted in significant episodes of illness (2). Table 3 shows that sewage is the leading contributor of contamination to water supplies (i.e., piped water, surface water, and groundwater), and that sewage contamination produces more cases of illness as compared to chemical and pesticide contamination. Untreated sewage usually contains large numbers of pathogenic microorganisms such as schistosomal ova cercaria and ova of parasitic flukes and worms; hepatitis A, bacterial dysentery, infectious diarrhea, *para*-cholera, and typhoid are also common (13). In 1991, the average incidence of typhoid fever was 10.6 per 100,000—any incidence greater than 10 per 100,000 is considered high by the World Health Organization.

The problems stemming from the failure to treat sewage properly are exacerbated by inadequate treatment of drinking water supplies. Of the 27 largest Chinese cities, only 6 supplied drinking water that met government standards; groundwater did not meet state standards in 23 of these cities (14). The situation is as bad or worse among rural towns and medium-sized cities. A survey of drinking water plants in Hubei Province found that only one in eight drinking water plants consistently treated water year round (15). Consequently, half the populations served by plants that failed to treat water regularly suffered from intestinal infectious disease between 1986 and 1988 (16). Therefore, even populations with access to tap water still face some risk of contracting diseases.

In addition to infectious diseases, higher rates of cancer mortality in urban areas have been tied to the lack of adequate sewage treatment facilities (16). Baoding City of Hebei Province constructed a sewage storage and drainage project that disposes of 250,000 tons of sewage per day in

Table 1. Ambient surface water quality classifications in China

Classification	Grade I ^a	Grade II ^b	Grade III ^c	Grade IV ^d	Grade V ^e
BOD ⁵	<3	3	4	6	10
Dissolved oxygen	90% ^f	6	5	3	2
Acidity (pH)	6.5	NS	NS	<8.5	6–9
Total phosphorous	0.02	L/R 0.025	0.1, L/R 0.05	0.2	0.2
Nitrates/nitrites	<10/0.06	10/0.1	20/0.15	20/1	25/1
Fecal coliform	NS	NS	10,000 U/l	NS	NS

Abbreviations: BOD⁵, biological oxygen demand; L/R, lake or reservoir; NS, not specified. Data from Wang and Wang (4).

^aMainly applicable to water sources and national nature reserve areas.

^bSuitable for grade I drinking water supplies, endangered fish reserves, and fish and shrimp breeding areas.

^cSuitable for grade II drinking water supplies, general fish reserves, and swimming areas.

^dMainly suitable for general industrial purposes and recreational uses that do not involve direct human contact with the water.

^eMainly suitable for agricultural uses and general scenic purposes.

^fSaturation rate.

Table 2. China's drinking water standards

Water quality	Parameters	Standards	
General and chemical characteristics	Color	<15 ^o ^a	
	Turbidity, in most cases	<3 ^o ^b	
	Turbidity, under special circumstances	<5 ^o ^b	
	pH	6.5–8.5	
	Total hardness (calcium carbonate)	450 mg/l	
	Volatile phenols	0.002 mg/l	
	Total dissolved solids	1,000 mg/l	
	Anionic synthesized sulfate	0.3 mg/l	
	Toxicity	Fluoride	1 mg/l
		Cyanide	0.05 mg/l
Arsenic		0.05 mg/l	
Mercury		0.001 mg/l	
Cadmium		0.01 mg/l	
Lead		0.05 mg/l	
Nitrogen (nitrates) ^c		20 mg/l	
Chloroform		60 µg/l	
Carbon tetrachloride		3 µg/l	
DDT		1 µg/l	
Bacteriological	Benzene hexachloride	5 µg/l	
	Total bacteria number	100 U/ml	
	Total coliform group	3 U/ml	
	Free chlorine residual		
	After dilution in ambient water	>0.3 mg/l	
At the tap	>0.05 mg/l		
Radioactivity	Total α and β radioactivity	0.11 Bq/l	

Data from Wang and Wang (4).

^aDegrees indicate light absorption of water.

^bDegrees measure light refraction, which indicates size and number of particles.

^cNo values are specified for nitrites or ammonium.

Baiyangdian Lake (17). A task force established by the provincial administration compared the quality of groundwater and the rates of cancer mortality near Baiyangdian Lake (the most polluted area) and along the drainage canal (polluted area) with those in a control area (Fig. 3). The three areas—control, polluted, and most polluted—were classified according to the relative degree of water quality in each area. For instance, the control area had 0 of 18 wells below Grade II, the polluted area had 2 of 24 wells below Grade II, and the most polluted area had 6 of 24 wells below Grade II. Among the three areas, cancer mortality was significantly higher among residents relying on contaminated groundwater (17). The rates of esophageal and liver cancer were three times that of populations in the studied control area (17). Populations in the Baiyangdian Lake area also exhibited higher incidences of anemia (i.e., the average number of cells lacking hemoglobin of <120 g/l were 1.32%, $p < 0.01$ higher in males, and 6.00%, $p < 0.01$ higher in females) and elevated immune responses (i.e., white blood cell counts in polluted areas were higher than control areas by an average of $7,027/\text{mm}^3$, $p < 0.01$) (17).

Intensification and Modernization of Agriculture

Inadequate drinking water and sewage treatment infrastructure is not the only problem plaguing urban water resources.

The rapid expansion of new agricultural activities, the so-called vegetable baskets (urban and suburban gardens), are also aggravating drinking water supply problems. These newly developed plots are usually irrigated with untreated sewage while fertilizer and pesticides are applied to raise productivity. Furthermore, poultry operations and small-scale household husbandry have also expanded rapidly to meet the demand of city residents for meat, eggs, and milk. These operations generate considerable animal waste within and around cities. Most of the wastes from these farms are discharged untreated into surface waters (18).

China's agricultural economy has undergone a rapid transformation in the last 15 years. Beginning in the 1980s farmers were permitted by the state to sell surplus produce on the open market. This created incentives to increase agricultural productivity and to adopt green revolution technologies: intensive fertilizer and pesticide application together with improved hybrid seeds. The National Environmental Protection Agency (NEPA) in Beijing reported that the use of fertilizers in China rose from 25.9 million tons in 1990 to 33.1 million tons in 1994 (6).

Despite the increased use of fertilizer, only 30% of fertilizers applied to agricultural crops are used effectively (19). As a result, nonpoint source pollution has been worsening dramatically. Excessive use of

fertilizers, the prevalence of phosphate-based detergents, and the discharge of human and livestock excreta into the lakes of intensively farmed provinces is leading to their eutrophication (overloading of water bodies with organic materials and nutrients that encourage algal blooms and deplete the oxygen available for aquatic organisms). The proliferation of algae has affected water supply sources and forced the temporary closure of drinking water plants (20). For example, Taihu, the third largest freshwater lake in China, has become a major sink of agricultural and rural effluents generated in Jiangsu and Zhejiang Provinces (21,22).

Algal blooms are also the source of a far more serious threat to human health: algal toxins. More than 80% of 480 algae samples taken from surface waters collected throughout China produced toxins (23,24). Many studies, including short-term assays, intact animal experiments, chronic feeding assays, and epidemiologic surveys, have demonstrated the etiological role of algal toxins, particularly microcystins and nodularin produced by blue-green algae, in pathogenesis of liver cancer (25,26). Even when the presence of hepatitis B viral infections, ethnic or genetic susceptibilities, and alcohol consumption were factored in, the risk of liver cancer associated with the consumption of polluted drinking water was still twofold or higher (27,28). Because these phytotoxins represent only a few of those probably present in eutrophied waters, this is important and disturbing evidence that merits urgent attention; in China, however, the study of pesticides has focused on managing or preventing poisoning or toxic events usually associated with accidental spills during application or transportation. Thus, there are limited epidemiologic data or other types of research performed on the possible ways that agrochemicals, particularly pesticides, could effect human health in China. There is also limited knowledge of whether bioaccumulation in plants and animals is entering the human food chain, or what levels of exposure affect immune system function (29).

Misapplication of fertilizers and pesticides is not the only agricultural practice adversely affecting water supplies, however. Acute water shortages, especially in the northern regions, have led to the relatively new practice of using industrial wastewater for irrigation. This interaction between industrial and agricultural activities and their impact on human health is highlighted by the problems in the Shenfu irrigation area near the heavily industrialized city of Shenyang in Liaoning Province (30,31). An irrigation canal was built in this area in the

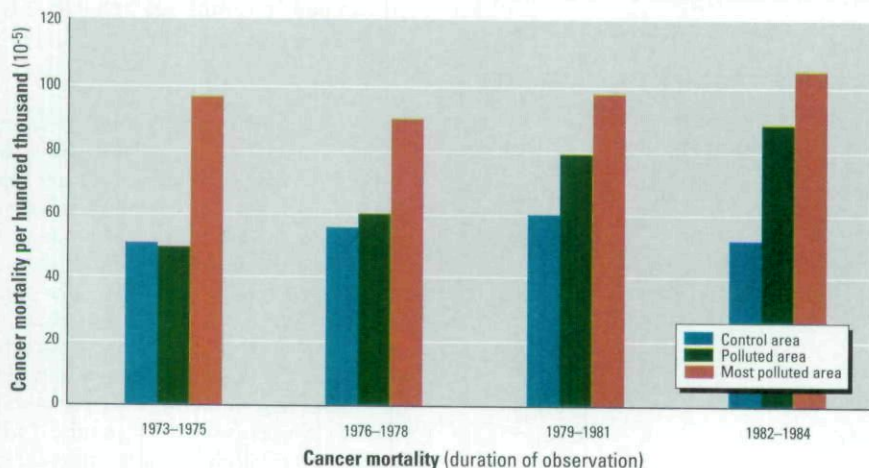


Figure 2. Cancer mortality from water pollution. Data from Deng et al. (30).

Table 3. Number of cases of illness associated with the contamination of water supplies

Pollutants	Piped water supplies		Other water supplies	
	Water source polluted	Negative pipeline pressure	Surface water	Groundwater
Sewage	27,031	9,469	8,138	1,245
Chemicals	3,196	185	2,323	603
Pesticides	1,071	0	835	0
Totals	31,298	9,654	10,996	1,848

Data from Cao and Xu (2).

early 1960s. The canal was 70 km in length and supplied 13,000 acres of land. Each day the canal drained an average 400,000 m³ of untreated wastewater from coal mines and petrochemical, power, and chemical plants. The area's cancer mortality and incidence of birth defects were investigated between 1973 and 1984. Figure 4 demonstrates that higher levels of cancer mortality and birth defects were found relative to the control area. In particular, the area served by the canal had approximately three times as many (34.2/10,000 versus 12.0/10,000) cases of liver cancer than the control area, lower average age of death from cancer, and approximately three times more birth defects (67.42 versus 20.07 per 1,000) than the control area.

Conclusions and Recommendations

The implications for China's environmental health risk transition of water pollution are quite significant. Although much of the evidence assembled is dated, often anecdotal, and of limited spatial or temporal scope, when taken as a whole it points to several possible consequences for public health. First, morbidity and mortality associated with infectious and parasitic diseases may not continue to decline, and may potentially increase. At the same time a more affluent and growing population, more intensive use of agrochemicals, and continued industrial expansion will increase the amount of human, animal, and industrial waste entering surface and groundwater streams. Second, the combined exposures to both traditional (infectious and parasitic) and modern (cancers, heart disease, and respiratory diseases) risks may be accelerating the incidence of diseases classified as noncommunicable. For example, stomach and liver cancers are linked to exposures of infectious agents (*Helicobacter pylori* and hepatitis B), and some of the studies have noted associations between gastric diseases and elevated cancer rates in areas irrigated with human excreta as well as industrial wastes. Third, the economic impacts of water pollution are far too severe for the Chinese government to continue to manage water resources in the traditional fashion. A study conducted by NEPA in the 1980s found that damage to human health from water pollution, mostly from the increase in the incidence of intestinal disease as well as gastric and liver cancers, accounted for 53.1% of the total economic losses due to water pollution. The World Bank estimates the impact of water pollution on human health is approximately \$3.9 billion per year (41.73 billion yuan). In sum, the evidence assembled indicates

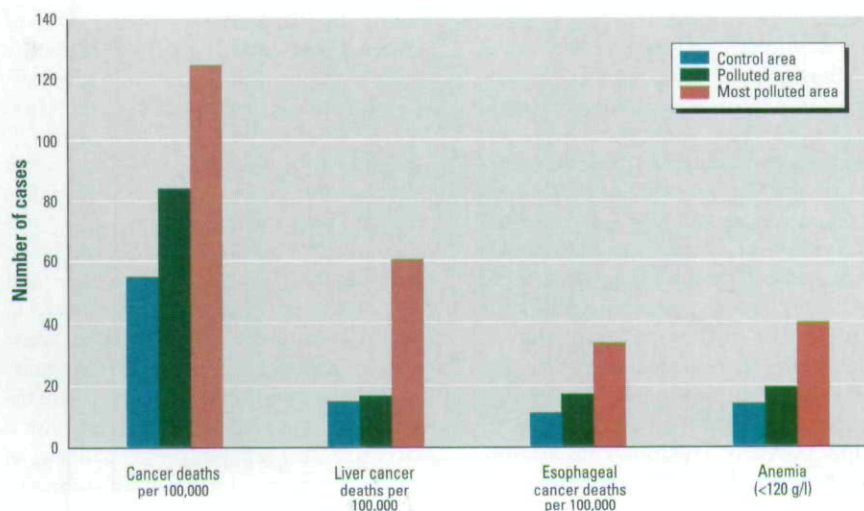


Figure 3. Cancer deaths and anemia from sewage storage, Baiyangdian Lake, China. Data from Hu (17).

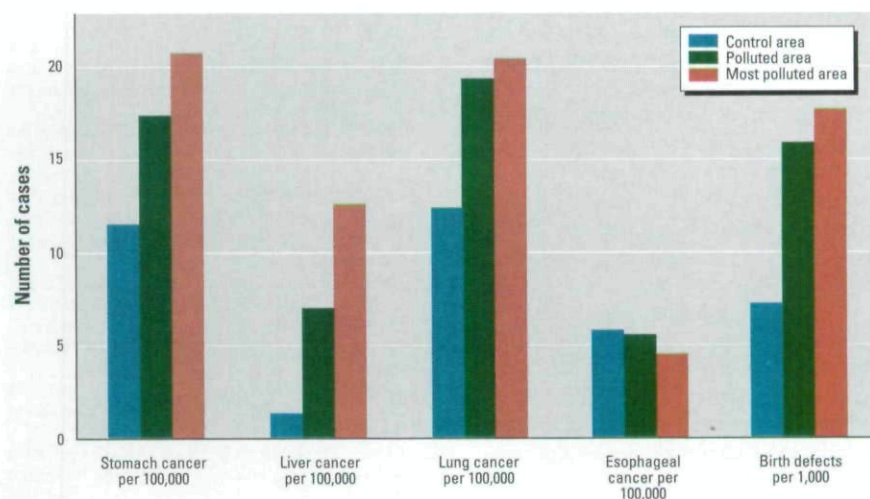


Figure 4. Cancer mortality and birth defects from water pollution, Shenfu irrigation area, China. Data from Deng et al. (30).

that water pollution is playing a significant role in shaping China's environmental risk transition. Attention to and correction of the water pollution problems discussed here would result in many public health benefits.

The conclusions and observations made in this paper point to priority areas for action or attention from public health authorities, environmental policymakers, and research institutions. One of the first priorities should be to elevate public health objectives within the current management framework. Within the overall framework established by the national Law of Water and the Law of Water Pollution Prevention (32), the protection of water quality and enforcement of water quality standards are under the NEPA (now called the State Environmental Protection Administration, or SEPA) jurisdiction. SEPA, however, must rely on local environmental protection bureaus (EPBs) within municipal and

county governments to enforce regulations, especially because government restructuring has reduced the size of SEPA by 40%. Responsibility for water quality management is further fragmented by the fact that surveillance of drinking water quality is the responsibility of the Ministry of Health (MOH, Beijing). The MOH monitors drinking water quality and waterborne diseases, primarily through the supervision and monitoring of environmental sanitation and health in public places, drinking water sources, and cosmetics. Little or no formalized coordination is in place between SEPA, the MOH, and local EPBs.

This separation of water resource management among development, pollution control, and public health agencies at the national and local level prevents integrated or coherent management of this resource. In effect, water is a common property resource suffering from a free-ride problem:

government agencies act like free riders as each seeks to maximize its own benefits or set of bureaucratic objectives. To address the public health and water problems, numerous policies should be considered. SEPA and other ministries with responsibility for shaping or overseeing developmental activities should weigh the potential health impacts of their management activities. Many mechanisms would need to be adopted to effectively raise the profile of public health objectives. The shared responsibilities of SEPA and the MOH for protection of human health should be institutionalized through the creation of working groups or scientific commissions to tackle specific areas of overlap and coordination (this might follow the example of the Committee on Reviewing the Safe Use of Pesticides, formed by the central government to regulate pesticide use). Other suggestions include integration of the MOH and local health bureaus or agencies into local or regional river basin commissions; discussion of public health issues in analyses of environmental quality that are part of annual state-of-the-environment reports; and mandated assessment of health impacts in the development of regional, county, or municipal development plans.

Even with these mechanisms in place, change cannot be implemented without comprehensive, continuous, and systematic research on water pollution and related health effects. In particular, this review suggests a need to focus on the following research areas: 1) the prevalence of algal toxins in surface water bodies and their impacts on health; 2) an evaluation of fertilizer and pesticide contamination in ambient and groundwater bodies, as well as identification of exposure routes (bioaccumulation in aquatic organisms and contamination of drinking water sources); 3) research on additive or synergistic effects on health created by the compounded effect of multiple pollutants; 4) monitoring of drinking water quality in conjunction with monitoring of disease morbidity and mortality within the seven river basin commissions; 5) development or expansion of existing regional or federal programs to monitor ambient and groundwater quality; and 6) dissemination of research information to regional and local bureaus (environmental and health) to assist with their decision making.

The Chinese government has already made a commitment to saving the country's

rapidly depleting water resources. One of its initiatives included increasing the investment in developing sewage engineering technology nearly threefold from 1991–1996 (6). In addition, a nearly 2-year-old national campaign against further deterioration of major rivers and lakes claimed victory when the Huai River was declared a clear water body. The campaign continues and is targeting other lakes and rivers. However, with the country moving toward a market economy, the Chinese decision makers and researchers face daunting challenges of not only how to strengthen the research, but also how to establish a legislative and regulatory mechanism, as well as a policy framework to guide the costly efforts of water pollution control.

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