Urbanization impairs surface water quality: eutrophication and metal stress in the Grand Canal of China

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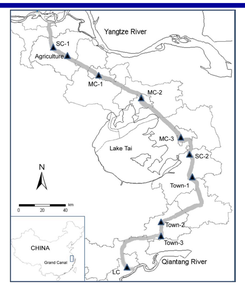
SUMMARY: China has achieved the most rapid urbanization in the world within the past three decades and its urban development is diverse at level. It provides a "vast experiment" to explore the process-based impairment mechanisms of surface water quality by urbanization. Nine towns and cities at various development levels along the historic Grand Canal (approximately 1500 years) in China were selected to reveal direct linkages between surface water quality and extent of urbanization. The selected towns and cities represent a gradient of urbanized population from 4,562 to 2,060,600 in 2007. Surface water quality in the urban sections of the Grand Canal was impaired by both eutrophic agents and metals. Although metals most remained at concentrations permissible to the Chinese National Environmental Standard for Surface Water Quality , the concentration and speciation of metals in the urban Canal could be related to local industrial activities. The level of urbanization, in this study, significantly related to water quality parameters in a descendent order of conductivity > nutrients > metals. This study suggests that significant mitigation strategies are required for the Grand Canal of China for a sustainable urbanization goal.

INTRODUCTION: The rapid urbanization has been resulting in surface water eutrophication and quality-oriented water resource shortage in China. An understanding of evolution of surface water quality with urban development is crucial for local governments to manage and protect surface water resources in an ecological and sustainable way for further urban planning. Case studies on water quality and quantity depletion by urbanization process in China will be useful as a reference for other developing countries with environmental problems caused by irrepressible rapid urbanization.

OBJECTIVES: This study on urbanization processes employed the method of space-for-time substitutions. A set of independent urbanized areas (3 countryside towns, 2 developing cities, and 4 well-developed cities) with the Grand Canal running through represent an urbanization gradient. We hypothesize that 1) the level of urbanization relates to surface water quality in the urban sections of the Canal, and 2) surface water quality might be directly fingerprinted by local economic composition or industry structure.

STUDY AREA: The south section of the Grand Canal, the world longest ancient canal (1,794 km in total, initial construction back to the 5th century BC and completed in the Sui Dynasty (581-618 AD)), runs through the Yangtze River Delta connecting with the Yangtze River in the north and the Qiantang River in the south. The Canal connects multiple cities and is used as a waterway for barge transportation of coal and construction materials between cities. The Canal is maintained by local water networks and also receives discharges from urban and rural catchments.



Classification for surface water quality of urban sections in the Grand Canal according to the Chinese National Environmental Standards for Surface Water Quality

Site	Agri	Town-1	Town-2	Town-3	SM-1	SM-2	MC-1	MC-2	MC-3	LC	China MEP Class III	US EPA CCC
No. Sample	4	5	4	5	5	7	10	17	16	14		
pH	I	I	I	I	I	I	I	I	I	I	6.0–9.0	6.5–9.0
Ammonia	II	IV	V	V	III	>V	V	V	>V	III	≤1.0	
Total N	>V	>V	>V	>V	>V	>V	>V	>V	>V	>V	≤1.0	
Total P	IV	IV	>V	V	IV	V	V	>V	V	IV	≤0.2 (river)	
Copper*	I	I	I	I	I	I	I	I	I	I	1000	9.0
Zinc*	II	II	II	II	II	II	II	I	II	II	1000	120
Lead*	I	I	I	I	I	I	I	I	I	I	50	2.5
Cadmium*	I	I	I	I	I	I	I	I	I	I	5	0.25
Chromium*	II	II	II	IV	II	II	II	II	II	II	50	11
Mercury*	I	I	I	I	I	I	I	I	I	I	0.1	0.77
Chloride	P	P	P	P	P	P	P	P	P	P	250	
Nitrate	P	P	P	P	P	P	P	P	NP	P	10	
Iron	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	0.3	
Manganese	P	NP	NP	NP	P	NP	P	NP	NP	P	0.1	

*Metals were in μg L^{-1} and others in mg L^{-1}.
--China Ministry of Environmental Protection (MEP). 2002. The National Environmental Standards for Surface Water Quality (GB3838).
--US Environmental Protection Agency (EPA). 2006. The National Recommended Water Quality Criteria for Priority Toxic Pollutants: criterion continuous concentration (CCC).

Canonical redundancy analysis for correlations between surface water quality and urbanization level along the Grand Canal, China.

Standardized Variance of the Surface Water Quality Explained by

Canonical Variable Number	Their Own Canonical Variables		Canonical R-Square	The Urbanization Level Canonical Variables	
	Proportion	Cumu. Proportion		Proportion	Cumu. Proportion
1	0.2435	0.2435	0.9951	0.2423	0.2423
2	0.0693	0.3129	0.9584	0.0665	0.3088
3	0.0751	0.388	0.9492	0.0713	0.3801

Standardized Variance of the Urbanization Level Explained by

Canonical Variable Number	Their Own Canonical Variables		Canonical R-Square	The Surface Water Quality Canonical Variables	
	Proportion	Cumu. Proportion		Proportion	Cumu. Proportion
1	0.1492	0.1492	0.9951	0.1485	0.1485
2	0.0269	0.1762	0.9584	0.0258	0.1743
3	0.1551	0.3313	0.9492	0.1472	0.3216

Squared Multiple Correlations Between the Surface Water Quality and the First M Canonical Variables of the Urbanization Level

	M	1	2	3
Basic property	pH	0.0021	0.3604	0.5319
	Dissolved oxygen	0.0000	0.0695	0.0889
	Conductivity	0.8776	0.8824	0.8863
	Salinity	0.9745	0.9769	0.9786
	Chloride	0.8474	0.8493	0.8701
Dissolved nutrient	Organic C	0.0139	0.0191	0.0700
	NH_4^+-N	0.3193	0.6203	0.6217
	NO_3-N	0.4372	0.4804	0.5309
	Total N	0.5586	0.5591	0.5841
	Reactive P	0.0857	0.1041	0.1118
	Total P	0.3054	0.3489	0.3616
Dissolved metal	Fe	0.0702	0.0767	0.0935
	Mn	0.0381	0.0722	0.5788
	Al	0.0012	0.0054	0.0138
	Cu	0.1029	0.2518	0.2518
	Pb	0.1243	0.1245	0.3580
	Zn	0.0037	0.0278	0.0389
	Cd	0.0179	0.0254	0.0974
	Cr	0.0092	0.1593	0.3702
	Hg	0.0577	0.1626	0.1632

Squared Multiple Correlations Between the Urbanization Level and the First M Canonical Variables of the Surface Water Quality

	M	1	2	3
Population	Total	0.0016	0.0087	0.2862
	Non-agriculture	0.0783	0.0784	0.3095
	Urbanization rate	0.1565	0.2868	0.6983
GDP	Total	0.0812	0.0865	0.2225
	Primary	0.5296	0.5470	0.5927
	Secondary	0.0292	0.0333	0.1959
	Tertiary	0.1413	0.1472	0.2514
	Industry	0.0219	0.0248	0.1961
GDP per capita	Total	0.1030	0.1470	0.2048
	Primary	0.5612	0.5735	0.7012
	Secondary	0.0618	0.0685	0.1163
	Tertiary	0.1107	0.2058	0.2699
	Industry	0.0543	0.0584	0.1355

RESULTS AND DISCUSSION:

Eutrophication is the primary impairment in urban sections of the Grand Canal

Surface water quality in the investigated urban sections of the Canal is classified at the Class V or above for TN and the Class IV or above for TP, according to the Chinese Standards. Both TN (5.02±1.57 mg N L^{-1}, mean±SD) and TP (0.38±0.15 mg P L^{-1}) in the investigated canal sections were much greater than in some urban streams in the USA (Tufford et al., 2003: Brett et al., 2005) and in China (Li et al., 2009).

The N loadings in the urban sections had lower NO_3^--N in proportion than in the agriculture section, ratio of NO_3^--N to NH_4^+-N ranging from 0.76 (SC-2) to 5.68 (SC-1) in contrast to 8.06 of the agriculture section, in an agreement with Groffman et al. (2004).

The investigated urban sections of the Canal were entirely eutrophic based on TP (the threshold level at 0.075 mg P L^{-1}) and TN (the threshold level at 1.5 mg P L^{-1}) by the classification of trophic states for freshwater streams (Dodds et al., 1998).

Metals in urban sections of the Canal related to local industry activity

Urban-oriented metals, Cu, Zn, Pb, and Cd , in surface water of urban sections of the Canal met the Class II of the Chinese Standards. The urban-oriented metal concentrations of the Canal were comparable with the River Tame in Birmingham, UK (Shepherd et al., 2006) and rivers in Northern Greece (Simeonov et al., 2003), and greater than the Yeongsan River, Korea (Kang et al., 2009), and much lower than the Guadiamar River in Spain (Alonso et al., 2004).

Aquatic communities might be impaired by urban -oriented metals in some urban sections of the Grand Canal classified by the criterion continuous concentration (CCC) for priority toxic metals (US EPA, 2006). For instance, the Town-3 canal might be impaired by Cr^{6+} ; SC-2 canal might be affected by Cu ; and MC-3 and SC-2 canals might be deteriorated by Hg.

Linking surface water quality in the Grand Canal to the urbanization level

The origin, speciation, and concentration of pollutants in surface waters correspond to local economic structure or industrial structure which drives material metabolisms in urban areas and determines waste constituents, such as the excess Cr from traditional tannery in Town-3, high Cu from recycling industry in SC-2, and detectable Hg from coal power plants in MC-3 and SC-2.

The GDP and per capita GDP from primary industry showed considerable correlation to surface water quality change while population urbanization rate, the GDP and capita GDP from tertiary industry slightly correlated to surface water quality according to the canonical analysis. Both primary industry and tertiary industry are suspectable to release nutrients to urban catchments altering surface water trophic status.

Overall, heavy metals were slightly impacted surface water quality in the Canal by urbanization in comparison with nutrients.