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Testing and Analyzing Surface Water Quality of Yue-Guan Canal in Yueqing, China

by

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With Honors

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APPROVED

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Abstract

The rapid industrialization in eastern China has made great contributions to the growth of the country's economy while also degrading the environmental quality. Yet the government is reluctant to release the environmental information to the public, resulting in a barrier for concerned citizens to participate. This study focuses on the water quality of Yue-Guan Canal in Yueqing, Zhejiang, where private rural enterprises have mushroomed since the 1980s. The objective of this study is to 1) test the water quality of the canal based on pH, total dissolved solids (TDS), copper (Cu), ammonia nitrogen (NH_3-N) and hexavalent chromium (Cr VI); 2) determine the relation between water quality and land use and land cover (LULC), and model the water quality of the whole canal based on LULC; and 3) make the information available to the public via an online geographic information system (GIS) platform. I chose six sampling sites along this 27 km canal, and collected samples on 3 workdays and 3 non-workdays in December 2012 and January 2013. I found an excess of NH_3-N made the water samples of all sites fail to meet the national standards for Class V water. I created regression models for pH, TDS and Cu in relation to LULC, but all resulted in low R^2 values, which may suggest point sources contribute more pollutants than non-point sources. I published the map and the data as a web application for the public.

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Acknowledgements

I would like to thank my dad, without whom I wouldn’t be able to collect the water samples so easily. I’m extremely grateful to Prof. Myrna Hall, who introduced GIS to me, took me to Onondaga Creek to collect and test water samples and patiently helped me with this thesis. I appreciate the useful advice from Dr. Lianjun Zhang regarding the regression. I also want to say thank-you to Dr. Wendong Tao, who kindly reviewed my thesis; and to the Honors Program, who provided me with the equipment and part of the funding.

Introduction

1. Water Quality in China

During the last two decades, a large area of China has been rapidly industrialized, especially along the east coast. Numerous factories are built to meet the domestic market demand and to export cheap commodities overseas. However, these factories bring heavy pollution to air, water and soil due to the neglect of externalities in economics and the ineffectiveness of environmental regulations. Although the air pollution of the country has become a huge concern both nationally and internationally in recent years (Shapiro, 2012), it might hinder the discussion of an equally severe pollution, if not more severe, which is that of water. As the title of a *Business Insider* gallery (Spector, 2013) reads, “If you think China's air is bad, you should see the water”, the rivers in China suffer from eutrophication, metal-ion dye, trash disposal and so on. In 2011, more than a third of Chinese rivers didn’t meet the Class III standards (Ministry of Water Resources, 2012). The Chinese surface water quality standards, GB3838-2002, classify the water bodies into 5 classes, with Class I-III being drinkable waters and Class IV & V being undrinkable (Table 1).

Table 1
Water Quality Classification in the National Surface Water Quality Standards GB3838-2002 (Ministry of Environmental Protection of China, 2002)

Class	Description
Class I	Mainly applicable to the source of water bodies and national nature preserves.
Class II	Mainly applicable to class A water source protection area for centralized drinking water supply, sanctuaries for rare species of fish, and spawning grounds for fish and shrimps.
Class III	Mainly applicable to class B water source protection area for centralized drinking water supply, sanctuaries for common species of fish, and swimming zones
Class IV	Mainly applicable to water bodies for general industrial water supply and recreational waters in which there is not direct human contact with the water.
Class V	Mainly applicable to water bodies for agricultural water supply and for general landscaping purposes.

According to Wang *et al.* (2008), the principle drivers of water pollution are growing municipal and industrial waste discharges and limited wastewater treatment capacity. In 2010, nearly 40% of the total wastewater discharged in China came from industrial sources and the remaining 60% from municipal sources. Both the percentage and the amount of municipal wastewater increased from 2005 levels (Table 2). In 2011, the Ministry first added ammonia nitrogen released from agricultural sources and centralized waste treatment facilities into the pollution survey. The municipal NH_3-N increased nearly 60% from the previous year, comprising 56.7% of total NH_3-N export, and the total NH_3-N export more than doubled from the 2010 level (Table 2). The huge hike was partially a result of new audit methods (Liu, 2013).

Table 2
Total Wastewater Discharged and Ammonia Nitrogen Released in China in 2005, 2010 and 2011, and Their Sources (Ministry of Environmental Protection of China, 2006, 2012 & 2013)

Item		2005		2010		2011	
Wastewater discharged (billion tonnes)	Industrial	24.31	46.3%	23.75	38.5%	23.09	35.0%
	Municipal	28.14	53.7%	37.98	61.5%	42.79	65.0%
	Total	52.45	100%	61.73	100%	65.88	100%
Ammonia nitrogen released (million tonnes)	Industrial	0.525	35.0%	0.273	22.7%	0.281	10.8%
	Municipal	0.973	65.0%	0.930	77.3%	1.477	56.7%
	Agricultural	/	/	/	/	0.827	31.8%
	Centralized	/	/	/	/	0.020	0.77%
	Total	1.498	100%	1.203	100%	2.604	100%

Although both volume and percentage of industrial wastewater discharged decreased from 2005 to 2011, it is usually more harmful to the environment due to the heavy metals involved in industrial processes (Li, 2012). Wang *et al.* (2008) state that most of the untreated industrial effluent comes from rural industry. Most rural enterprises are characterized by their small scale, outmoded technology, obsolete equipment, poor management and heavy consumption of water resources (Qu and Li, 1994). These township and village enterprises are difficult to regulate. Chinese scientists have stated that they have no means of controlling the pollution from these small-scale enterprises (Economy, 2010).

2. Environmental Information

Principle 10 of the Rio Declaration on Environment and Development (United Nations (UN) Conference on Environment and Development, 1992) states "… each individual shall have appropriate access to information concerning the environment … States shall facilitate and encourage public awareness and participation by making information widely available". The Aarhus Convention (UN Economic Commission for Europe, 2008) recognizes that "improved access to information and public participation in decision-making enhance the quality and the implementation of decisions, contribute to public awareness of environmental issues, give the public the opportunity to express its concerns and enable public authorities to take due account of such concerns".

However, it is not easy to obtain accurate environmental quality data in China. Although there are environmental monitoring stations at provincial, prefectural and county levels, relatively little information is available about local environmental quality in most townships and villages (Tilt, 2010). When available, some of the data are modified so they appear better (Shapiro, 2012; Ghanem & Zhang, 2013). It is also common for the government not to disclose the environmental information, even upon citizens' requests (Yang, 2012; Gong, 2011). The *Measures on Open Environmental Information (for Trial Implementation)* came in effect on May 1, 2008 (EPA-China Environmental Law Initiative, 2013) and it aims to "speed up the transition from conventional government-dominated environmental regulation to a more transparent and modern environmental governance system". It requires both environmental authorities and industries to disclose environmental information. But the implementation fell short, according to Zhang *et al.* (2010). The authors identified the following factors leading to the poor implementation through interviews: shortcomings in capacity, training of staff, unclear procedures and responsibilities and lack of information etc.

Volunteer testing of air quality boomed across the country in 2012 when air quality around Beijing reached its worst and the public's discontent and distrust against the authorities grew

(LaFraniere, 2012; Stout, 2013). Volunteer testing of water quality also became a hot topic. These initiatives have an educational value and promote public engagement within environmental protection (Gouveia *et al.*, 2004). For example, Yan (2012) reported that the volunteers of *Green Hunan* conducted water quality testing regularly and pushed for solutions to the pollution problems. One of them found a company illegally discharging wastewater and posted the information online, leading to a public apology from the company.

Most environmental information has a spatial component, meaning it can be shown on a map. With technological advancement in the GIS field, web-based GIS applications become an effective way to present and to communicate. An example of an existing web-based GIS application in China is the pollution map published by the Institute of Public and Environmental Affairs (IPE). Jun Ma, the founder of IPE and a Goldman Environmental Prize winner in 2012, organized the monitoring and enforcement data from the Chinese government to make it available to the public through online air and water pollution maps (Goldman Prize, 2012). The public database urged many local and multinational corporations to take measures to meet the emission standards.

3. The City of Yueqing and Yue-Guan Canal

The City of Yueqing provides an example of rural industrialization and pollution. It is a county-level city under the administration of Wenzhou City in southeastern China. It is administratively divided into 8 sub-districts and 9 towns. The city’s GDP in 2011 was 57.15 billion yuan (9 billion US dollars in 2011), with the industrial sector contributing 60.6% (Statistical Bureau of Yueqing (SBY), 2012a). According to the latest statistical information (SBY, 2012b), the gross industrial output value (IOV) of enterprises above designated size (industrial enterprises whose annual revenue exceeds 20 million yuan) in October 2012 reached 8.76 billion yuan ($1.4 billion). The two towns with the highest IOVs were Liushi and Beibaixiang, whose IOVs comprised 37.8% and 24.5% of the total IVO of the city, respectively.

Liushi Town sits in the southern part of Yueqing, with a local resident population of 215 thousand and immigrant worker population of 240 thousand. It is where the "Wenzhou Model" originated (Wang & Wei, 2011), one of the three distinct types of rural industrialization in China (Wang *et al.*, 2008). Free development of private enterprises (mostly household undertakings) is one of the characteristics of the model (Byrd *et al.*, 1990). Small household workshops flourished in the 1980s, when the central government allowed privatization, and most of them were involved in electrical parts manufacturing. Today, Liushi is awarded as the "capitol of low-voltage electrical equipment production" in the country. Beibaixiang Town, compared to Liushi, has a more diverse industry. Besides low-voltage electric equipment, other major industries are furniture, clothing, mechanical manufacturing and building materials.

There is an extensive network of waterways in this coastal city, especially in the southern part, where the estuary and plain are the dominating landforms. The waterways provide irrigation water for the rice paddies and simultaneously serve as open sewer to receive discharge from loosely regulated rural industries such as small plating workshops. According to the *2011 Report on the State of the Environment in Yueqing* (Environmental Protection Bureau of Yueqing (EPBY), 2012), none of the plain streams met the water quality standards. The main pollutants were chemical oxygen demand (COD), NH_3-N and total phosphorous. The water quality upstream was generally better than downstream. The surface water was worse than Class-V water by Chinese standard GB3838-2002. Class-V is a classification with the lowest requirement, applicable to water bodies for agricultural use and general landscaping purposes (Ministry of Environmental Protection of China, 2002).

Yue-Guan Canal (Figure 1) is one of the plain streams. It starts in the downtown in Yuecheng Sub-district, flowing through Chengnan Sub-district and Liushi Town, and enters Ou River in Beibaixiang Town. Because there is little elevation difference between the ends of the canal, the water mostly stagnates. The LULC along the canal is comprised mostly of agricultural land (rice paddies), forest and developed area (residential, industrial etc.). However, due to the nature of

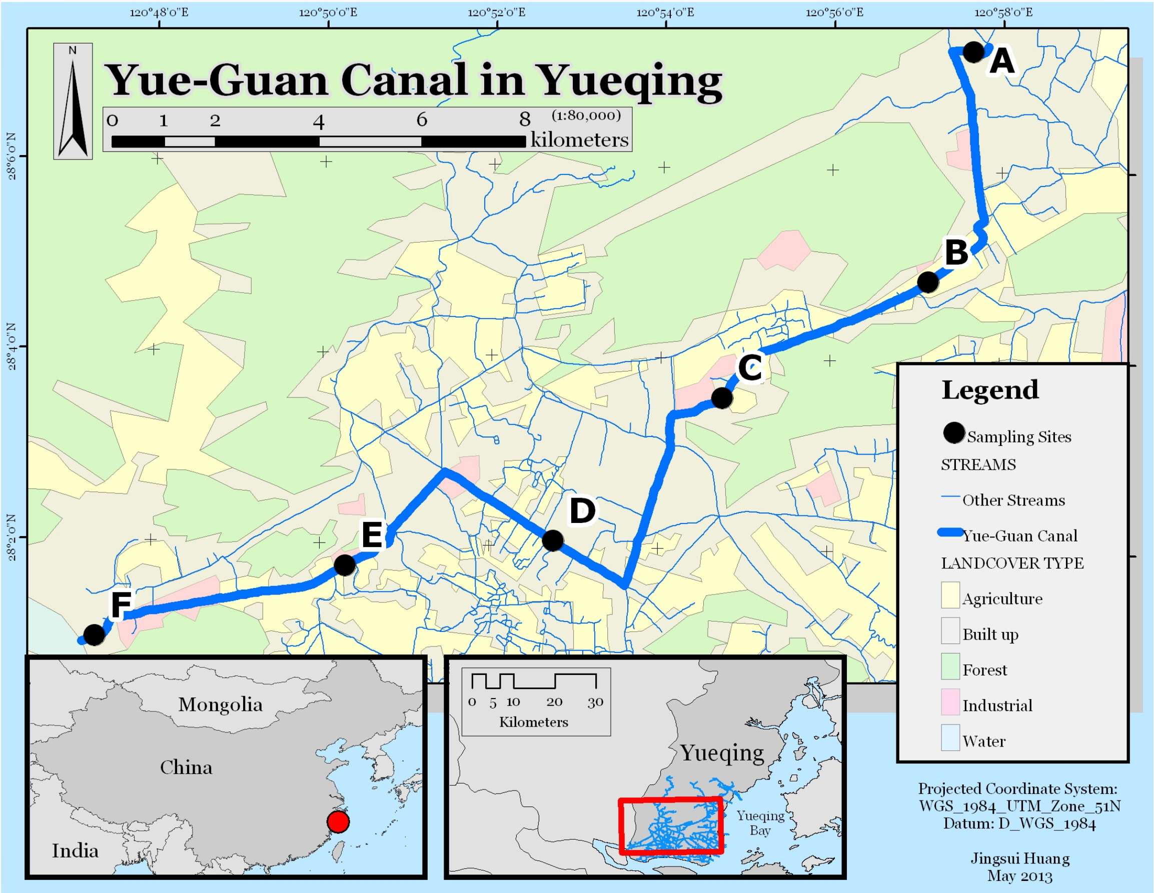


Figure 1 Map showing the canal, sampling sites and LULC

rural industries, they are often not distinguishable from residential buildings.

Pan & Huang (2009) studied the agricultural nonpoint source (NPS) pollution in the city based on the data collected in 2000. They found the main causes of the pollution were human waste, rice paddy runoff, residential solid waste, residential wastewater and fisheries. They also pointed out that the industrial pollution was far more severe than the agricultural NPS pollution and it was the dominating source of pollution. Song *et al.* (2012) evaluated the heavy metals in rivers in Wenzhou, which is south of Yueqing. They found the heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Zn) concentrations were highest in industrial area, followed by urban area. Few studies have been done to study the water quality in Yueqing, so I feel it would be interesting to see the status of pollution in the streams of the city.

4. Relation between Land Use and Land Cover (LULC) and Water Quality

The terrestrial LULC patterns of a watershed have a great impact on the water quality of the streams in it. Modeling water quality based on LULC has been the objective of many studies (Table 3). The two main approaches to calculate percentage of LULC (%LULC) are sub-watershed (or catchment) LULC and riparian zone LULC. To calculate the %LULC in a sub-watershed, the whole area contributing hydrologically to the sampling site (pour point) is determined first. To calculate the %LULC in a riparian zone, a buffer of certain distance to the stream on both sides is created first. Sliva & Williams (2001) assessed these two approaches for three southern Ontario watersheds and concluded the sub-watershed approach appeared to have slightly greater influence on water quality. They also found urban land use was the most important predictor of water quality variability. Pratt & Chang (2012) drew a more affirmative conclusion, stating the sub-watershed approach "clearly generated a stronger model" than the riparian approach. However, Tran *et al.* (2010) compared the two approaches as well and suggested stronger correlation between water quality and LULC in 200-m riparian zone than that in sub-watershed. They also found that urbanization and agriculture significantly influenced stream water quality. Ahearn *et al.* (2005) found %Agriculture had a significant influence on nitrite-N and TSS. Mouri *et al.* (2011) found %Urban was positively associated with BOD, TN, TP and TSS while %Forest was negatively associated with the four parameters. Li *et al.* (2012) found the contribution of %Agriculture to the concentration of TDS was the highest. Li *et al.* (2008) found negative correlation between pH and %Urban, and between NH_3-N and %Vegetation (non-agricultural). They also found positive correlation between NH_3-N and %Water and %Bare land. Su *et al.* (2013) revealed differing determinants and regression equations for each water quality parameter using both %LULC approaches in 1996 and 2003. They didn't find relationships between Cr VI and LULC. Tu (2011) did a gradient analysis across metropolitan Boston and the surrounding forests. He found varying relationships between %LULC and water quality in less- and highly-urbanized area.

5. Objectives

The objective of this project is to 1) quantitatively analyze the water quality of Yue-Guan Canal based on the following physical and chemical parameters: pH, TDS, Cu, NH_3-N and Cr VI; 2) model the water quality of the whole canal based on LULC; and 3) make the information available to the public on web-based GIS platform.

Table 3

List of Studies of Modeling the %LULC and Water Quality

Study	Approach	Location	Dependent Variables	Independent Variables Considered
Sliva & Williams (2001)	1) Sub-watershed 2) 100-m riparian	Southern Ontario, USA	DO, T, Alkalinity, Fecal coliform count, Cu, Ammonium, Phosphate, Cl, Total Solids, Nitrate	1) field; 2) forested land; 3) agricultural land; 4) urbanized land; 5) sand–gravel–silt deposits; 6) sand; 7) silt–clay deposits; 8) silty-sand till deposits; 9) slope
Tran *et al.* (2010)	1) Sub-watershed 2) 200-m riparian	Upper & lower Hudson Valley and Champain, NY, USA	T, pH, DO, EC, Nitrite, Nitrate, TP, TSS, Fecal coliform count, Species richness, Hilsenhoff Biotic Index, Percent Model Affinity, EPT, Biological Assessment Profile	1) forest; 2) urban; 3) agriculture
Ahearn *et al.* (2005)	Sub-watershed	Cosumnes Watershed, CA, USA	Nitrate-N, TSS	1) agriculture; 2) forest; 3) grassland; 4) urban; 5) population density
Mouri *et al.* (2011)	Sub-watershed	Shigenobu River, Shikoku, Japan	BOD, TN, TP, TSS	1) forest; 2) paddy field; 3) plantation; 4) urban area; 5) river area; 6) field; 7) golf links; 8) lake; 9) seashore; 10) transportation network; 11) other land use
Li *et al.* (2012)	Sub-watershed	Liao River, NE China	pH, T, EC, BOD, COD, Sediment amount, Habitat evaluation, Nitrite-N, NH_3-N, Nitrate-N, TN, TP, Phosphate, TDS, Hardness	1) agricultural land; 2) forestry land; 3) grassland; 4) water body; 5) urban-rural residential land; 6) bare land
Li *et al.* (2008)	Sub-watershed	Han River, Central China	T, DO, pH, ORP, EC, Turbidity, TDS, Nitrate–N, NH_3-N	1) vegetated land; 2) agriculture; 3) urban; 4) waters; 5) bare lands
Su *et al.* (2013)	1) sub-watershed 2) 500-m riparian	Qiantang River, Zhejiang, China	Petroleum, Cr VI, Total Cd, Total Hg, Total cyanide, Total Pb, Volatile phenol	1) water; 2) forest; 3) farmland; 4) build-up; 5) population density; 6) GDP; 7) deviation of slope; 8) average slope; 9) elevation; 10) distance to river source
Tu (2011)	Sub-watershed	Boston and surroundings, MA, USA	Specific conductance, TDS, Ca, Mg, K, Na, Cl, Sulfate, Phosphate, NH_3-N, Nitrite-N, Nitrate-N, KN, P	1) agricultural; 2) forest; 3) commercial; 4) industrial; 5) recreational; 6) residential
Pratt & Chang (2012)	1) sub-watershed 2) 100-m riparian	Portland, OR and Clark County, WA, USA	EC, DO, Nitrate-N, pH, TP, Total Solids, T	1) urban; 2) forest; 3) agriculture; 4) wetlands; 5) %SFR; 6) SFR age; 7) street density; 8) mean elevation: 9) StDev slope; 10) mean slope

DO: Dissolved oxygen; **EC**: Electrical conductivity; **EPT**: Ephemeroptera, Plecoptera, and Trichoptera taxa; **KN**: Kjeldahl nitrogen; **ORP**: Oxidation–reduction potential; **SFR**: Single family residential; **T**: Temperature; **TN**: Total nitrogen; **TP**: Total phosphorous; **TSS**: Total suspended solids

Methods

1. Testing Parameters

Based on the variety of the LULC types along the river, their expected pollutants, and the availability of scientific equipment, the following parameters are selected for this study:

- pH, or negative log of hydrogen ion concentration, measures the acidity/alkalinity of the water sample. It ranges from 0 to 14. The lower the pH, the more acid the water is.
- Total dissolved solids (TDS) are dissolved solids in water sample that can pass through a filter with pore size of 2 microns (EPA, 2012c). According to Cooke (unknown), TDS test is used as an indicator test to determine the general quality of the water and high concentrations of TDS may reduce water clarity, contribute to a decrease in photosynthesis, combine with toxic compounds and heavy metals, and lead to an increase in water temperature. Also, the concentration of TDS affects the water balance in the cells of aquatic organisms. The imbalance will make it difficult for fish to keep their position in the water column (EPA, 2012c). In the US, EPA (2012b) lists TDS under secondary drinking water regulations with a secondary maximum contaminant level (SMCL) of 500 ppm. TDS don't pose health risks even beyond SMCL, but they have aesthetic effects and technical effects, related to odor, taste, color, corrosion and sediments. In China, TDS is not listed in surface water standards (GB3838-2002) but in drinking water quality standards (GB5479-2006) with a limit of 1000 ppm.
- Copper (Cu) is an essential trace element in plant and animal metabolism. Most waters contain copper at levels not known to have any human or aquatic toxicological effects. Concentrations of copper result from metal plating, mining, pesticide production and electrical products industries. (EPA, 1988)
- Ammonia nitrogen (NH_3-N) includes both ionized form (ammonium, NH_4^+) and unionized form (ammonia, NH_3). Ammonia reduces dissolved oxygen in water because it exerts

nitrogenous biological oxygen demand (NBOD) as bacteria oxidize ammonia into nitrate and nitrite. Ammonia also leads to eutrophication, disrupting the original ecosystem. Sources of ammonia include manure application, concentrated animal feeding, landfill leachate, fertilizer use, urban runoff etc. (EPA, 2012a)

- Hexavalent chromium, Cr (VI), is one of the two significant forms of the element, the other being trivalent chromium, Cr (III). Compared to Cr (III), Cr (VI) is more soluble in natural water and is more toxic. Chromium is rare in natural waters, but it may come from the wastewater of electroplating, leather tanning, textile industries etc. The background levels in water average 1 ug/L while municipal drinking water contain 0.1-35 ug/L. Higher values of Cr can be related to sources of anthropogenic pollution. Long-term exposure to Cr above 0.1 mg/L may cause damage to liver, kidney circulatory and nerve tissues and dermatitis. (EPA, unknown)

2. Testing and Analysis

To determine my sampling sites, I first created a shapefile showing the canal as a line features in ArcGIS based on the Bing Aerial Basemap. I split the line feature into 5 equal-length parts so I got six points. I marked these six points *A* through *F*, with *A* being the most upstream and F being the most downstream (Figure 1). I adjusted the actual sampling sites in the field so I could have access to water relatively easily and safely.

The sample collection took place on December 22nd, 2012, and January 2nd to 5th, and January 7th, 2013, totaling 6 days, among which 3 days (1/4, 1/5, 1/7) were workdays and 3 days were non-workdays (public holiday or weekends, 12/22, 1/2, 1/3). There was light rain throughout the collection days. I followed the order of *C*, *B*, *A*, *F*, *E*, *D* to collect samples for route optimization and time saving. At each site, I took three 100-ml samples. It was cold enough (4-9 °C) so I didn't have to put the samples on ice. I measured the air temperature, water temperature, pH and TDS *in situ*. I brought all the 18 samples (6 sites × 3 samples/site) collected in one day to the lab for testing. The tools and equipment I used are listed in Table 4. I filtered 50 ml of each sample using Whatman® GF/F Grade filters before the tests.

Table 4
Testing Methods for Each Parameter

Parameter	Method	Tool	Testing Scheme
pH	Single-junction pH Sensor	Eutech Waterproof Multi-parameter Tester PCSTestr 35	Tested on-site at every site every day
TDS	Conductivity	Eutech Waterproof Multi-parameter Tester PCSTestr 35	Tested on-site at every site every day
Cu	Bicinchoninate	Thermo Orion AQ3700 portable colorimeter	Tested every sample for every day
NH_3-N	Salicylate	Thermo Orion AQ3700 portable colorimeter	Tested every sample for every day
Cr^{6+}	Diphenylcarbazide	Hach Chromium Color Disc Test Kit, Model CH-8	Tested one sample per site for every day

I calculated the average value of each parameter at each site and compared them to the National Surface Water Quality Standards for Class V water.

Because three of the six sampling days were workdays and the other three were not, I performed ANOVA analyses to see whether there is a significant difference in water quality between workdays and non-workdays after I checked the data normality (using data in Table 10). Since I also want to know if there are water quality differences between different sites, I did two-way ANOVA analyses for each of the parameters.

The null hypotheses are:

H_0: There is no significant difference in the concentration (pH, TDS, Cu, NH_3-N & Cr) between workdays and non-workdays at α=5%.

H_0’: There is no significant difference in the concentration (pH, TDS, Cu, NH_3-N & Cr) between different sampling sites at α=5%.

Then I created the LULC map for the areas that are within 3 km from the canal by looking at the Bing aerial images available as a Basemap layer in ArcGIS. I categorized the land into four classes: Agricultural, Built, Forest and Industrial. Agricultural land is mostly rice paddies. Built area includes everything that is built by human, except the agricultural land and industrial land. Because many industrial activities happen in residential areas, it is difficult to separate "industrial" from "residential". For the purpose of this study, the "Industrial" land represents explicit industrial land that is planned by the city planners (Housing and Urban-Rural Planning and Development Bureau of Yueqing, 2009).

I calculated Pearson's correlation coefficients between the %LULC and parameters that were significantly different between sites, for each of the three buffer approaches (Figure 2): 1) 1-km buffer, a circular buffer around the sampling site with a radius of 1 km; 2) 2-km buffer, a circular buffer around the sampling site with a radius of 2 km; 3) segment, a riparian buffer with a distance of 500 m to each side of the canal, segmented by the sampling site and the site immediately upstream. The 500 m distance can keep the general information and reduce the noise of LULC, given that certain LULC type may become too homogeneous when the distance is too short (Su *et al*., 2013). Also due to terrain homogeneity, it was not possible to create a true upslope contributing sub-watersheds.

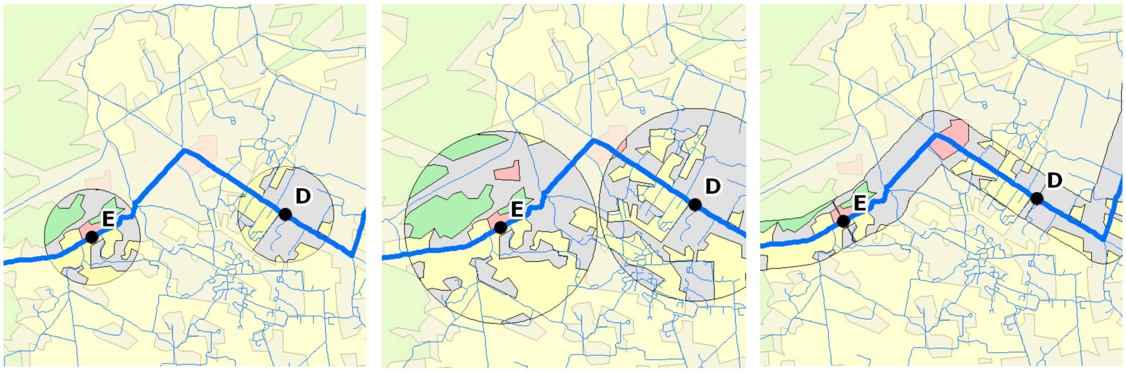


Figure 2 Three different approaches of %LULC calculation (from left to right): 1-km buffer; 2-km buffer; segment

I determined the best %LULC calculation method based on the number of variable pairs that were significantly correlated. I dropped all the pairs that had a R^2 less than 0.1. I assumed other pairs had linear relationships and I used these pairs to perform multi-linear regression using Data

Analysis tool in Excel.

3. Publishing Data Online

I created a shapefile for each of the parameters, storing the testing results at each site on each day in the attribute table. I registered an Esri Global Account and an ArcGIS Public Account to create web maps and web applications. I uploaded the following layer onto ArcGIS Online (www.arcgis.com): pH, TDS, Ammonia, Cu, Sampling Sites, Streams, Yueqing City and Contour. I configured the display settings and shared it as a web application so that everyone with Internet access can see the results.

Results

1. Testing Results

None of the water samples from the six sites met the National Surface Water Quality Standards for Class V water because of an excess of NH_3-N (Table 5). The NH_3-N levels are one to two times more than the maximum level allowed. Site *C* has the highest NH_3-N concentration. The water at Site *A* ~ *D* is a little basic while the water at Site *E* and *F* is a little acidic. The lowest pH measurement took place at Site *E* on 12/22/2012 (Table 10 in Appendix). TDS exhibits a general increasing trend from Site *A* to *F*, except the lower TDS at Site *E*. We see the highest

Table 5
Mean Values of Each Parameter at Each Site and the National Standard for Class V Water

Site	pH	TDS (ppm)	Cu (mg/L)	NH_3-N (mg/L)	Cr VI (mg/L)
A	7.28	147.83	0.05	4.71	0.00
B	7.58	262.17	0.15	5.23	0.00
C	7.39	290.17	0.14	6.17	0.00
D	7.23	318.33	0.09	4.68	0.02
E	6.43	283.83	0.26	4.35	0.00
F	6.84	357.17	0.28	4.41	0.00
Standard	6-9	N/A	≤1.0	≤2.0	≤0.1

Cu concentrations at Site *E* and *F*, which correspond to lowest pH values. Only one of the 36 Cr VI testings showed measurable result (Table 10 in Appendix), so I neglected this parameter in the following analyses.

2. Analyses and Modeling

A p-value less than 0.05 leads to the rejection of the null hypothesis H_0 and H_0'. Because the p-values from pH vs. Site and TDS vs. Site are less than 0.05 (Table 6), I reject the H_0 for pH and TDS. There is significant difference in pH and TDS between different sites at α=5%. There is no significant difference in Cu or NH_3-N between different sites at α=5%. In terms of workdays and non-workdays, none of the parameters show differences. The 2-km buffer method shows the most correlations between water quality and %LULC and there are only two pairs of variables are significantly correlated in 1-km buffer method (Table 7). I find significant positive correlation between pH and %Forest, between TDS and %Industrial and between Cu and %Industrial from the 2-km buffer results. I also find significant negative correlation between pH and %Industrial, between TDS and %Built, and between Cu and %Built. There are no significant correlations between NH_3-N and %LULC in any of the three methods, so I dropped it in regression analyses.

Table 6
The p-Values from the ANOVA Analyses

Source of p-value	pH	TDS	Cu	NH_3-N
Site	0.000	0.001	0.084	0.719
Work-/Non-workday	0.533	0.289	0.810	0.363

None of the water quality and LULC pairs shows strong linear relationship (Maximum value of R^2 = 0.21) (Figure 3-14).

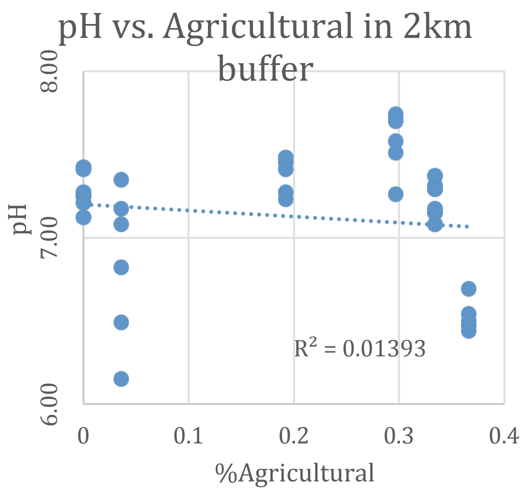
Table 7

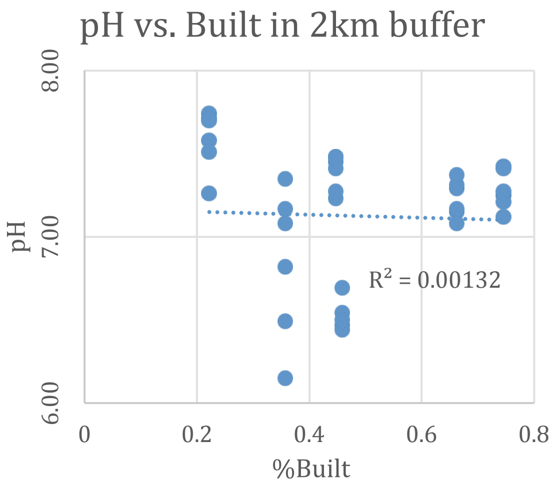
Correlation between Water Quality and LULC

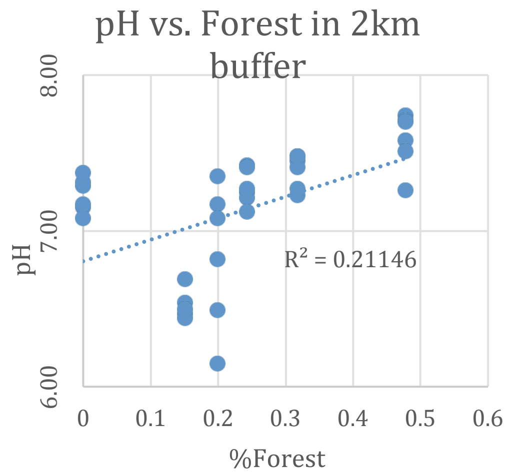
Variable Pairs		1 km buffer	2 km buffer	segment
pH	%Agricultural	0.100	-0.118	-0.042
	%Built	0.037	-0.036	0.021
	%Forest	0.106	0.460[a]	0.193
	%Industrial	-0.086	-0.365[b]	-0.500[a]
TDS	%Agricultural	0.173	0.232	0.060
	%Built	-0.448[a]	-0.351[b]	0.430
	%Forest	0.138	-0.212	-0.538[a]
	%Industrial	0.295	0.365[b]	0.553[a]
Cu	%Agricultural	0.000	0.066	-0.075
	%Built	-0.343[b]	-0.343[b]	0.263
	%Forest	0.256	-0.000	-0.267
	%Industrial	0.204	0.340[b]	0.476[a]
NH_3-N	%Agricultural	0.107	0.010	-0.124
	%Built	-0.102	-0.067	0.193
	%Forest	0.071	0.167	-0.031
	%Industrial	0.184	0.018	-0.128

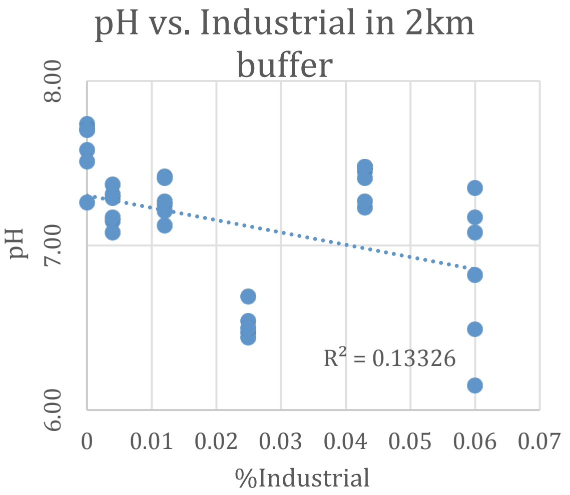
a: significant at 0.01 level

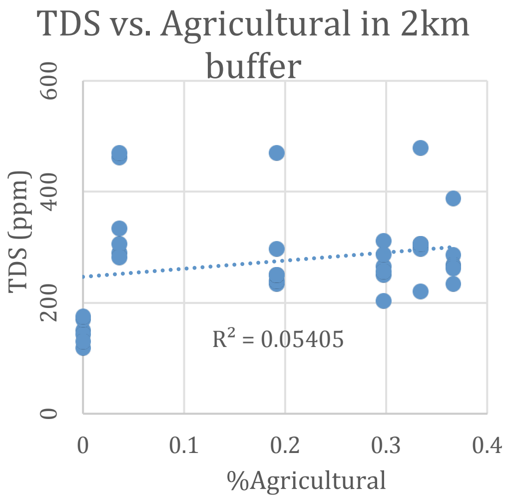
b: significant at 0.05 level

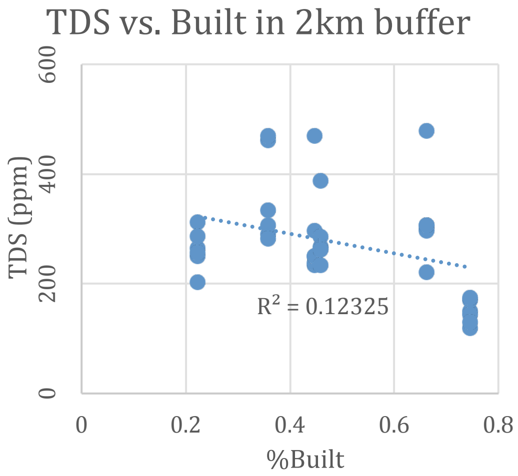


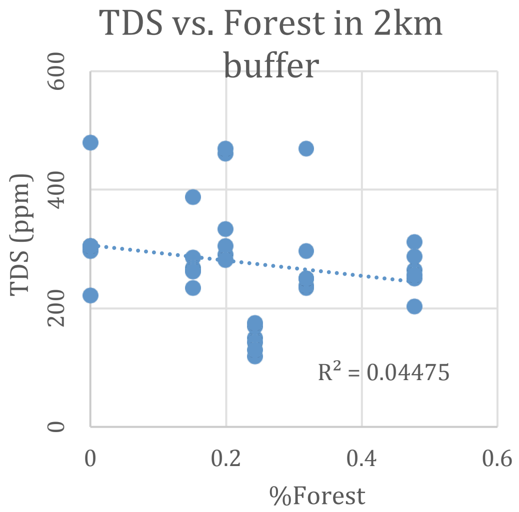


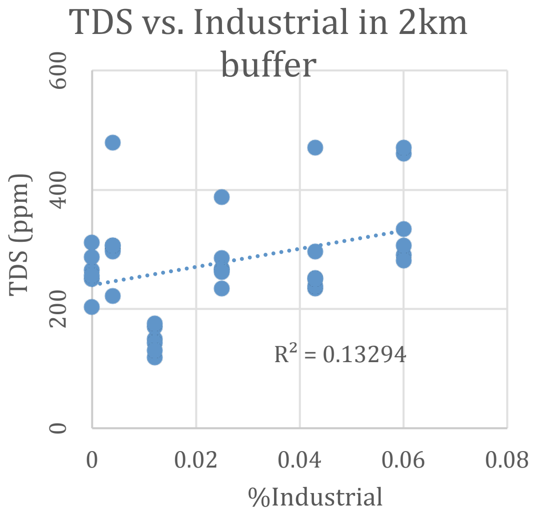

pH vs. Forest in 2km buffer
pH
8.00
7.00
6.00
0
0.1
0.2
0.3
0.4
0.5
0.6
%Forest
R² = 0.21146

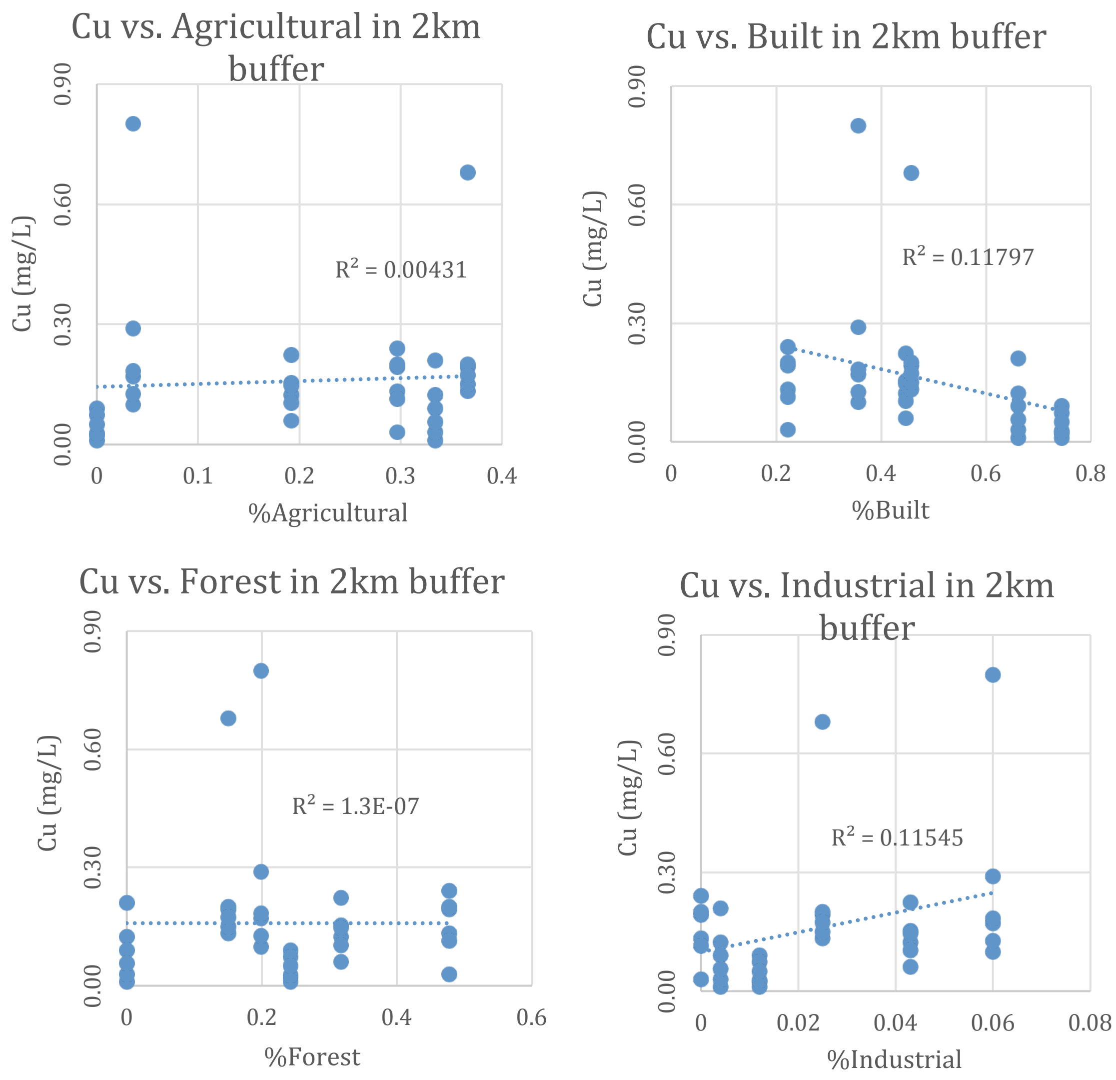

pH vs. Industrial in 2km buffer
pH
8.00
7.00
6.00
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
%Industrial
R² = 0.13326


TDS vs. Agricultural in 2km buffer
TDS (ppm)
600
400
200
0
0
0.1
0.2
0.3
0.4
%Agricultural
R² = 0.05405


TDS vs. Built in 2km buffer
TDS (ppm)
600
400
200
0
0
0.2
0.4
0.6
0.8
%Built
R² = 0.12325


TDS vs. Forest in 2km buffer
TDS (ppm)
600
400
200
0
0
0.2
0.4
0.6
%Forest
R² = 0.04475


TDS vs. Industrial in 2km buffer
TDS (ppm)
600
400
200
0
0
0.02
0.04
0.06
0.08
%Industrial
R² = 0.13294



Figures 3-14 Scatter plots of pH, TDS & Cu vs. %LULC

The regression yielded the following models (Table 8):

pH = 6.986 + 1.325 (%Forest) – 6.99 (%Industrial)

TDS = 314.967 – 140.950 (%Built) + 1230.459 (%Industrial)

Cu = 0.230 – 0.247 (%Built) + 1.985 (%Industrial)

However, all models have low R^2 values and adjusted R^2 values.

3. Published Data

The URL of the web-based application is http://bit.ly/11Qc2gv. The viewer can zoom in or

Table 8

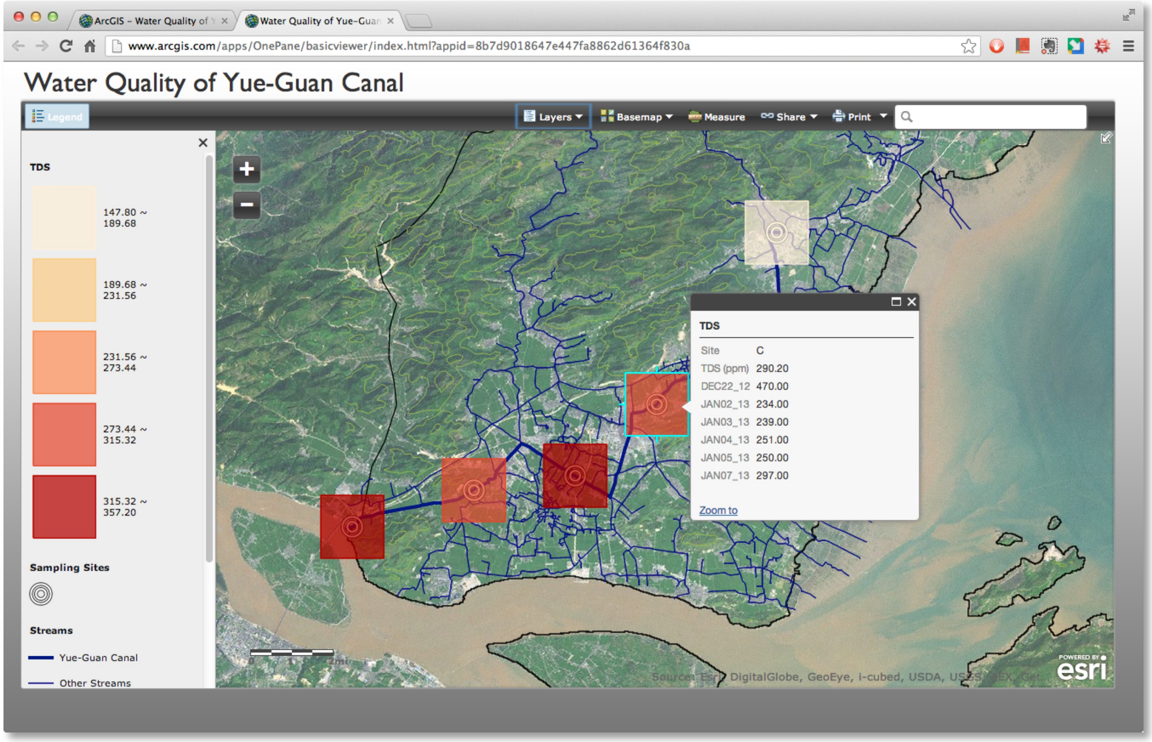
Results of Regression

Parameter	R^2	Adjusted R^2		Coefficient	p-Value
pH	0.327	0.287	Forest	1.325	0.004
			Industrial	-6.99	0.023
			Intercept	6.986	0.000
TDS	0.205	0.157	Built	-140.950	0.093
			Industrial	1230.459	0.075
			Intercept	314.967	0.000
Cu	0.187	0.137	Built	-0.247	0.099
			Industrial	1.985	0.105
			Intercept	0.230	0.011

out to the desired scale, select from a variety of Basemaps and choose what layer(s) to be displayed. Figure 15 is a screenshot showing the TDS layer over the Streams layer and Imagery Basemap. The viewer can also click on the parameter symbols (colored squares) to see detailed data, which include the average concentration of the parameter at the site and each measurement with date.

Discussion

The low R^2 and adjusted R^2 values mean weak correlations between water quality and LULC. It may suggest point sources (rural enterprises) contribute more pollutants than non-point sources (rural and urban runoff). In this case, more appropriate methods should be used to distinguish the pollution from point and non-point sources. It can also be caused by the coarse LULC classification. A better model would require more accurate classification of higher resolution. The correspondence between the low pH and high Cu concentrations can be explained by 1) the solubility of Cu increases when pH decreases (EPA, 2013), and 2) there is illegal discharging of industrial effluent from the metal plating workshops around Site *E* & *F*. According to the *Company Environmental Supervision Records* available on IPE's website (2013), there are three metal plating workshops that have violation records in the vicinity: Kuyan, Xiangta and Huifeng. They were fined and marked as black or red in environmental credit rating system.



TDS

Site	C
TDS (ppm)	290.20
DEC22_12	470.00
JAN02_13	234.00
JAN03_13	239.00
JAN04_13	251.00
JAN05_13	250.00
JAN07_13	297.00

Figure 15 Screenshot of the published application

In the summer of 2012, a group of graduate students from Zhejiang University tested the water quality and air quality near an industrial zone in Baishi Town, which is west to Liushi and Beibaixiang. Sun (2012) reported much more severe pollutions (Table 9). Site 1 and Site 2 were on the tributary connecting the industrial land and a main stream where Site 3 and Site 4 were. She concluded that the industrial effluent contained mostly organic pollutants and some heavy metals. The large differences between her results and mine can probably be explained by seasonal variations and choice of sampling sites.

Table 9

Water Quality Reported by Sun (2012)

Site	1	2	3	4
pH	8.79	8.69	7.51	7.01
NH_3-N (mg/L)	53.74	48.86	11.81	0.32
Cr VI (mg/L)	0.1577	0.1440	0.1310	0.1220
Cu (mg/L)	4.1911	2.9017	0.4227	Not detected

In the process of sample collection, I discovered suspicious wastewater discharging activities underwater near Site *C*. An unknown source discharged yellowish wastewater intermittently and irregularly into the canal. However I couldn't tell if that was untreated industrial water. The color indicated it possibly contained iron ions, for which I didn't have the testing reagents. I reported it to EPBY. The law enforcement arrived at the scene but the discharging paused so they didn't see. There was no follow-up development of the issue after I returned to the US.

After I completed the testing, I submitted a public information request to EPBY, trying to obtain all the monitoring data they had for Yue-Guan Canal. At first the official agreed and asked me to get them in person. I visited the office only to find out they "made a mistake". I had a long talk with the head of the environmental monitoring station. He refused my request, citing concerns over my "lack of credential", "unnecessary panic of the public", "incomplete interpretation of the data", large cost and so on. He showed me some internal documents on the environmental quality but forbid me to take notes. From the talk I learned that they started regular water quality testing along the canal about two years ago at seven sampling sites. They tested the water samples for ammonia-nitrogen, COD(Mn), total phosphorous, iron, chromium and copper. Finally he agreed to provide me with annual average values of selected parameters, which were to be determined by upper-level officials. I received the selected data the next week. They were annual average values for ammonia-nitrogen, COD(Mn) and total phosphorus at each site in 2011 and 2012. I can compare only NH_3-N values to my study. The lowest NH_3-N concentration they reported is 7.88 mg/L and it was recorded at Nanmen Bridge in 2012, which is close to site *A* in this study. This annual concentration is almost twice as the average at site *A* found in this study (4.71 mg/L). This can possibly be explained by continuous precipitation on the sampling days and seasonal variation. Sampling and testing water quality in summer can be the next step.

There is a municipal wastewater treatment plant (WWTP) in the city. It began operating in 2007 with a capacity of 80,000 tonnes of wastewater per day. However, whether it is working is questionable. According to IPE database (2013), this facility had been reported to discharge treated water that didn’t meet the effluent standards. It would be interesting to study the effect of the WWTP on water quality as the city constructs more extensive infrastructure to divert the wastewater into the WWTP.

A recent study by Dr. Tsanangurayi Tongesayi shows imported rice in the US contains harmful levels of lead, with the rice from China and Taiwan having the highest lead levels (Palmer, 2013). Because rice is grown in heavily irrigated conditions, it is more susceptible than other staple crops to environmental pollutants in irrigation water, which is usually raw sewage effluent and untreated industrial effluent in China. Future studies of the canal may include the lead levels in water, in the rice paddies along the canal and in the harvested rice from these rice paddies.

Although the Mao era is long gone and environmental issues are not as sensitive as human rights issues, there still exist political risks for some citizens and citizen groups concerned about the environment. Shapiro (2012) listed some examples in her book. Lake Tai activist Lihong Wu was sentenced in 2007 on trumped-up charge of extortion and blackmail. Kai Tan, founder of “Green Watch” (declared as illegal organization) which focused on water pollution in Zhejiang, was arrested in 2005 for “illegally obtaining ‘state secrets’”. As recent as February 2013, a 60-year-old villager Yuqian Chen was beaten after calling on the officials to swim in polluted streams (Phillips, 2013). As I saw in EBPY, a lot of environmental information is still classified as “secret” (the least confidential among secret, highly secret and top secret, which are the three classes of secret related to state security and national interests). Therefore obtaining and publishing environmental information may invite the police. For instance, China accused US embassies of illegally publishing air quality information (Branigan & Reuters, 2012). Although I haven’t had these problems so far, future environmental quality testing should be practiced with caution.

The published web-based GIS application offers flexibility and clarity. However, it is only available in English by the time this paper is finished. Besides the language, the lack of data also prevents the public visiting the application. Future modifications to the application can include query functions if more (daily or weekly) data are incorporated. By then a formal assessment of the effectiveness of the application can be done.

Conclusion

By testing the concentrations of pH, TDS, Cu, NH_3-N and Cr VI at six sampling sites along Yue-Guan Canal for six days in winter, I found the main pollutant was NH_3-N. pH was higher upstream than downstream, where more rural industries involving metal processing were located. Cu concentrations were higher downstream, possibly due to the industrial effluent. TDS exhibited an increasing trend upstream to downstream, likely due to the increasing salinity as it got closer to the ocean. Cr VI was not found except at one site on one day, suggesting possible illegal discharge of industrial wastewater.

Among the three methods for calculating %LULC, the 2-km buffer method gave me the best correlation between water quality and LULC. No significant correlation was found between NH_3-N and LULC. The regression models had low R^2 values and I considered them too weak to be valid. It can be probably explained by the larger contribution of point source pollution than non-point source pollution and low resolution of the LULC classification.

My testing results were accessible at http://bit.ly/11Qc2gv. The web-based GIS application's impact on public remained limited due to language and lack of data.

As the city is improving the wastewater treatment infrastructure and the public becomes more aware of the environmental quality, I believe the water quality will get better and the government will be more open and transparent towards the environmental information.

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Appendix

Table 10

The Results of Each Individual Testing. NH_3-N and Cu Concentrations Are the Averages of the Three Tests at the Site on the Sampling Day.

Site	Date	Workday (W)/ Non-workday (NW)	pH	TDS (ppm)	NH_3-N (mg/L)	Cu (mg/L)	Cr VI (mg/L)
A	12/22/2012	NW	7.25	150	5.37	0.02	0
A	01/02/2013	NW	7.21	143	3.07	0.01	0
A	01/03/2013	NW	7.27	119	3.27	0.09	0
A	01/04/2013	W	7.42	130	3.37	0.07	0
A	01/05/2013	W	7.12	170	8.40	0.03	0
A	01/07/2013	W	7.41	175	4.80	0.05	0
B	12/22/2012	NW	7.26	312	8.23	0.13	0
B	01/02/2013	NW	7.74	203	3.33	0.03	0
B	01/03/2013	NW	7.58	250	5.67	0.19	0
B	01/04/2013	W	7.71	265	3.53	0.11	0
B	01/05/2013	W	7.51	256	6.30	0.24	0
B	01/07/2013	W	7.70	287	4.33	0.20	0
C	12/22/2012	NW	7.48	470	11.27	0.22	0
C	01/02/2013	NW	7.45	234	4.33	0.12	0
C	01/03/2013	NW	7.41	239	3.13	0.10	0
C	01/04/2013	W	7.48	251	4.03	0.15	0
C	01/05/2013	W	7.23	250	9.07	0.06	0
C	01/07/2013	W	7.27	297	5.20	0.15	0
D	12/22/2012	NW	7.29	479	10.07	0.01	0
D	01/02/2013	NW	7.31	301	4.27	0.03	0
D	01/03/2013	NW	7.37	306	3.93	0.21	0
D	01/04/2013	W	7.15	297	3.37	0.12	0.1
D	01/05/2013	W	7.08	306	3.77	0.09	0
D	01/07/2013	W	7.17	221	2.67	0.06	0
E	12/22/2012	NW	5.92	388	5.33	0.68	0
E	01/02/2013	NW	6.47	286	4.57	0.19	0
E	01/03/2013	NW	6.69	268	4.53	0.13	0
E	01/04/2013	W	6.54	265	3.67	0.15	0
E	01/05/2013	W	6.44	262	5.13	0.20	0
E	01/07/2013	W	6.50	234	2.87	0.17	0
F	12/22/2012	NW	6.49	461	6.60	0.29	0
F	01/02/2013	NW	7.35	290	3.77	0.10	0
F	01/03/2013	NW	7.17	306	4.10	0.17	0
F	01/04/2013	W	6.15	470	4.47	0.80	0
F	01/05/2013	W	6.82	334	3.97	0.18	0
F	01/07/2013	W	7.08	282	3.57	0.13	0