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Esophageal cancer spatial and correlation analyses: Water pollution, mortality rates, and safe buffer distances in China

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Abstract: Esophageal cancer exhibits one of the highest incidence and mortality rates in China. Malignant tumors caused by esophageal cancer, and the relationship to environmental factors has been the focus of many public health studies. This study applied spatial analysis to ascertain the relationship between water pollution and esophageal cancer mortality rates nationwide. We employed two datasets, including a national investigation of esophageal cancer rates and distribution, and national water quality grades in China's primary rivers and lakes. Esophageal cancer data were grouped based on different water quality grades, which included a scaled buffer distance from rivers and lakes. Non-parametric correlation analyses were performed to examine the presence or absence of the following correlations: (i) esophageal cancer mortality and buffer distance from rivers and lakes; and (ii) esophageal cancer mortality and water quality grade values. The present study revealed a significant positive correlation between widespread water pollution and esophageal cancer mortality nationwide; and a significant negative correlation between esophageal cancer mortality, and buffer distance from rivers and lakes.

Keywords: esophageal cancer; water pollution; environment; GIS; spatial analysis

1 Introduction

Esophageal cancer is one of the most common human malignant tumors worldwide. The World Health Report 2004 ranked esophageal cancer as the highest cause of cancer mortality in China. Among the 446,000 cases of death caused by esophageal cancer worldwide, more than half occurred in China, i.e. 228 thousand (WHO, 2004). A national sample survey of malignant tumor mortality conducted between 2003 and 2006 showed the esophageal cancer mortality rate ranked fourth in China, following gastric, liver, and lung cancers. In recent years, the rapid economic growth in China has amplified the increasingly polluted waters in

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several main rivers and lakes, resulting in substantial threats to the health of residents living adjacent to these ecosystems (Van Grinsven *et al.*, 2006; Kenneth *et al.*, 1987; Wang and Liu, 2006; Chang, 2006; Hu *et al.*, 2009; Song *et al.*, 2008; Zhen *et al.*, 2008). To date, it has not been definitively established if pollution is a major risk factor for esophageal cancer on a national scale. Consequently, specific measures at the national level to counter the effects of water pollution, and reduce/prevent esophageal cancer rates have not been implemented. Therefore, medical geography research (Yang *et al.*, 2010), which identifies the degree of health effects and associated geographic patterns, will serve to examine water pollution in major rivers and lakes of China, the relationship with increased rates of esophageal cancer, and establish any significant correlation between increased pollution and disease. Disease prevention is of primary importance to elucidate pathogenesis, and formulate strategies and countermeasures to prevent and treat esophageal cancer in China.

Research on cancer risk factors remains the foundation and focus of cancer prevention and treatment investigations (Zhang and Wang, 2009; James, 1999; Brownstein *et al.*, 2002; Gatton *et al.*, 2005; David *et al.*, 2012). Presently, risk factor research is focused on poor eating habits (Lei *et al.*, 2006), smoking and other unhealthy lifestyles (Liu *et al.*, 2006), stress and other mental health and illness factors (Pan, 2006), the absence of trace elements in diets (Yang, 2009; Huang *et al.*, 2002), upper gastrointestinal disease history (Yang *et al.*, 2008), genetic predisposition for various cancers (Luan *et al.*, 2010; Liu *et al.*, 2008), economic conditions (Tong *et al.*, 2007), and food contamination and carcinogens in the local environment, including water (Farhad *et al.*, 2009; Nobuaki *et al.* 1996; Li *et al.*, 2006). Most studies on the relationship between esophageal cancer and water pollution reflect the individual case specifics in a distinct geographic region (Han *et al.*, 2007; Wang *et al.*, 2007; Zhu *et al.*, 2010; Shen *et al.*, 2002; Wei *et al.*, 1999; Soliman *et al.*, 2006). Some studies have conducted spatial-temporal analyses of esophageal cancer (Jacob *et al.*, 2008; Nuria *et al.*, 2007; Mohammadreza *et al.*, 2011), particularly the relationship between high localized incidence of esophageal cancer and environmental degradation of major drainage systems at the national scale. Previous research on environment and malignant tumor-related issues primarily adopted traditional approaches, including epidemiological investigations (Baudouin *et al.*, 2002), statistical analyses of risk factors in specific medical populations (James, 2004; Manami *et al.*, 2006; Zhou *et al.*, 2006), and laboratory testing (Peng *et al.*, 2005; Li *et al.*, 2008), among other methods. Two major differences have been identified between these two approaches. One method emphasizes statistical parameters to explain a relationship (Liao *et al.*, 2012; Kulldorff, 2005) between risk factors and malignant cancers. This methodology serves an important role in determining the mechanisms that influence cancer and the spatial threshold range of cancer and its risk factors (Liu *et al.*, 2003; Li *et al.*, 2006). Unfortunately, policy dictates that some studies must apply administrative divisions as research units, which prevent the effects of rivers, lakes, and other natural topographical units as risk factors in cancer research (Jiang *et al.*, 2009; Li and Wang, 2005). In recent years, a combination of traditional statistical methods and spatial analyses has facilitated enhanced understanding of the relationship between disease and the environment (Kate *et al.*, 2008; Rogers and Randolph, 2003; Melissa *et al.*, 2011; Hubbard *et al.*, 2002; Wang *et al.*, 2006).

The present study served to establish spatial associations between water degradation and pollution, and esophageal cancer mortality rates on a national scale in China by combining medical statistics with spatial analyses. The spatial threshold included water polluted major rivers and lakes, and the surrounding waterways to assess the impacts on human esophageal cancer mortality rates.

2 Methods

2.1 Esophageal cancer spatial distribution data from 2003 to 2006

Esophageal cancer mortality data were obtained from the China Ministry of Health. The National Sample Survey Dataset from 2003–2006 indicated 213 counties (municipalities and districts), including 116 urban sampling sites, and 97 rural sampling sites were selected in the study. Figure 1 provides the sample spatial distribution, including urban and rural sample esophageal mortality rates distributed throughout China, and the water quality grade in regional water sources.

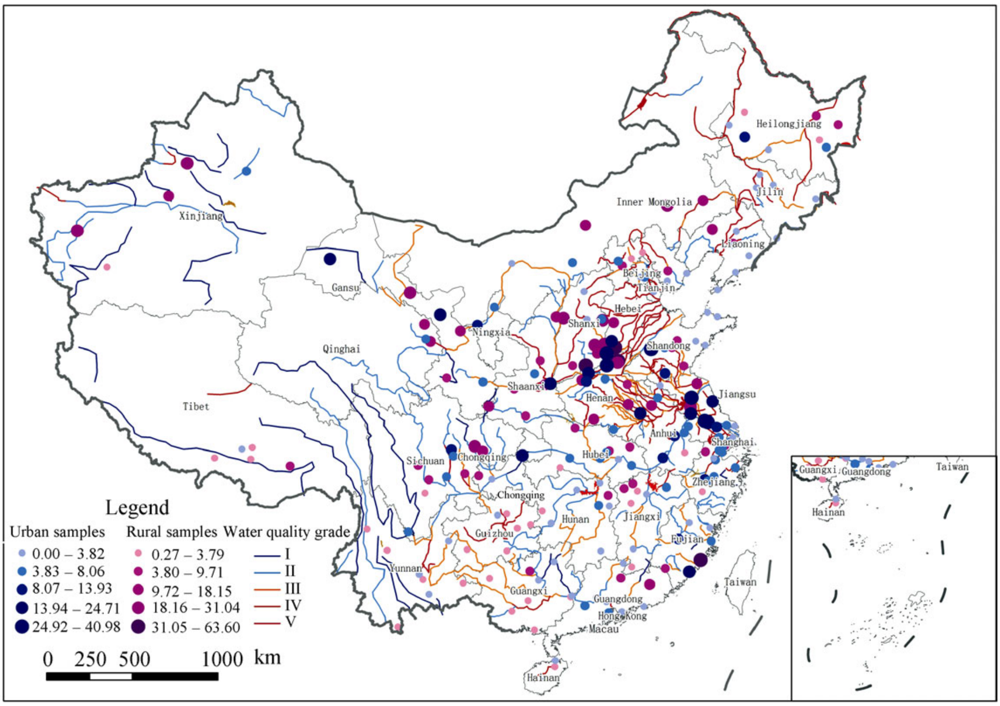

Figure 1 Esophageal cancer mortality distribution and water quality in rivers and lakes in China

The Haihe and Huaihe river drainage basins exhibited high esophageal cancer mortality rates. Many regions showed high esophageal cancer mortality, including Cixian, Huixian, Junxian, and Yancheng counties, and Linzhou, Huaian, Taixing, Yangzhong, and Feicheng cities. Data indicated populations distributed adjacent to various river and lake drainage basins in southwest China had lower average esophageal cancer mortality.

2.2 Water quality data

The China Ministry of Environmental Protection (MEP) provided water quality data. The earliest published national water quality data was in 2007, which is one year later than the national esophageal cancer investigation period 2003–2006. Consequently, we recognized limitations existed in examining a relationship between the two datasets. MEP and the State Environmental Protection Agency (SEPA) delimited five water quality grade levels in China on a scale from I to V; where grades I-III indicate water safe for human consumption following treatment, grades IV-V are safe for industrial and irrigation use, and grade V+ refers to water that is unsafe for any purpose, and in some cases, the water may be unsafe to touch. The primary water pollution indicators in rivers and lakes are total nitrogen and phosphorus. The general water quality conditions in rivers and lakes in China are presented in Figure 1. Seven major river systems are moderately polluted in China. Water quality data sampled from 407 sections that pertained to a network of 197 rivers, and found 49.9% and 51.1% were respectively classified in grades I to III and grades IV and V+. The Yangtze River is generally considered to maintain good water quality, however the Songhua River shows slight pollution, Yellow and Huaihe rivers are moderately polluted, and Liaohe and Haihe rivers suffer from heavy pollution. The 28 key state-controlled lakes and reservoirs exhibited 7.1% at Grade II; 21.4% at Grade III; 14.3% at Grade IV, including Jingpo, Dongting, Poyang and Xingkai lakes; and 57.2% at Grade V, including Chaohu, Nansi, Taihu, Dianchi, Baiyangdian, Dalai, Hongze, West, East, Xuanwu, and Daming lakes, and Laoshan Mountain, Dahuofang, and Yuqiao reservoirs.

2.3 Basic hypotheses

We established the following basic hypotheses to examine the effects of water pollution on esophageal cancer mortality at the 116 urban, and 97 rural sampling sites described in section 2.1.

We assumed people used untreated river and/or lake water, or untreated groundwater as the primary source of drinking water. Due to distance cost, the number of people fetching water from a river reach is inversely proportional to the distance from the reach, i.e. the closer a population is to a river, the greater the probability water will be fetched from that water source. Alternatively, as the distance from a river and population increases, a concomitant decrease occurs in the probability a population will fetch water from that river. People will choose alternative sources of water if rivers and lakes are not close geographically. Furthermore, the impacts of infiltration resistance result in the contamination of groundwater from adjacent polluted rivers and lakes, which is also inversely proportional to the distance from rivers and lakes. Beyond a certain distance, water contamination exhibits no effect on groundwater quality. Therefore, it is necessary to determine a distance threshold. If lake and river pollution do in fact affect esophageal cancer mortality rates within this threshold among people fetching drinking water from river or groundwater, then we propose the following hypotheses:

(1) Water pollution has increased the effects on esophageal cancer mortality rates in populations living adjacent to polluted river or lake sources; while populations residing further away from polluted water sources are at less risk of increased mortality rates due to eso-

esophageal cancer.

(2) Mortality rates due to esophageal cancer are higher among people that ingest and have exposure to highly polluted river and/or lake water; and mortality rates due to esophageal cancer are lower among people that ingest and have exposure to cleaner river and/or lake water.

2.4 Grouping model of river and lake water quality grade – buffer distance

We can test the above hypotheses by spatially modeling the sampling site environmental differences and esophageal cancer mortality rates among sites, i.e. levels of MEP/SEPA classified water pollution data, and mortality rates derived from the Ministry of Health surveys. Based on the distance from river and lake water infiltrating into the groundwater, we also needed to investigate differences between mortality rates from sampling sites at various distances from rivers and lakes, and differences among sampling sites with a range of water pollution grades (I-V+). We applied ArcGIS 10 and spatial analyses (Wang *et al*., 2000; Leung and Kwong, 1993), designed two different grouping models:

2.4.1 Grouping according to the buffer distance from rivers and lakes

The practical distance for fetching water from various river and lake channels was 20 km, which was therefore set as a distance threshold. A total of 10 buffer zones were established for each river and lake, with each buffer zone arranged at a 2 km interval. Grouping based on esophageal cancer mortality and buffer distance from rivers and lakes was expressed as:

$$d_p = i_{i\in 1...10}$$

where p represents the esophageal cancer mortality survey sampling site; and d_p is the grouping according to the buffer distance from the sampling site to the river or lake. Subsequently, the sampling sites for the esophageal cancer mortality survey were assigned to 10 buffer zones with different distances from the rivers and lakes.

2.4.2 Grouping according to the water quality grade

SEPA water quality grades I through V were used as a reference. Near function was applied in the spatial analysis approach to assign the esophageal cancer mortality survey sampling site to the nearest water quality grade group, which was expressed as:

$$c_p = j_{j\in 1...5}$$

where p represents the esophageal cancer mortality survey sampling site; and c_p is the grouping according to the water quality grade. Subsequently, the esophageal cancer mortality survey sampling sites were assigned to one of the five water quality grades.

Based on the different water quality grades and buffer distances, the Haihe River Basin was chosen as a model in this study. SS of the spatial analysis is presented in Figure 2.

There are 10 buffer zones marked by light green to deep green, at 2 km intervals. Due to serious water pollution, Grade I was not reported in the Haihe River Basin.

3 Results

3.1 Correlation between esophageal cancer mortality and the distance from rivers and lakes

Spatial computation was used to establish ten buffer zones for major rivers and lakes in

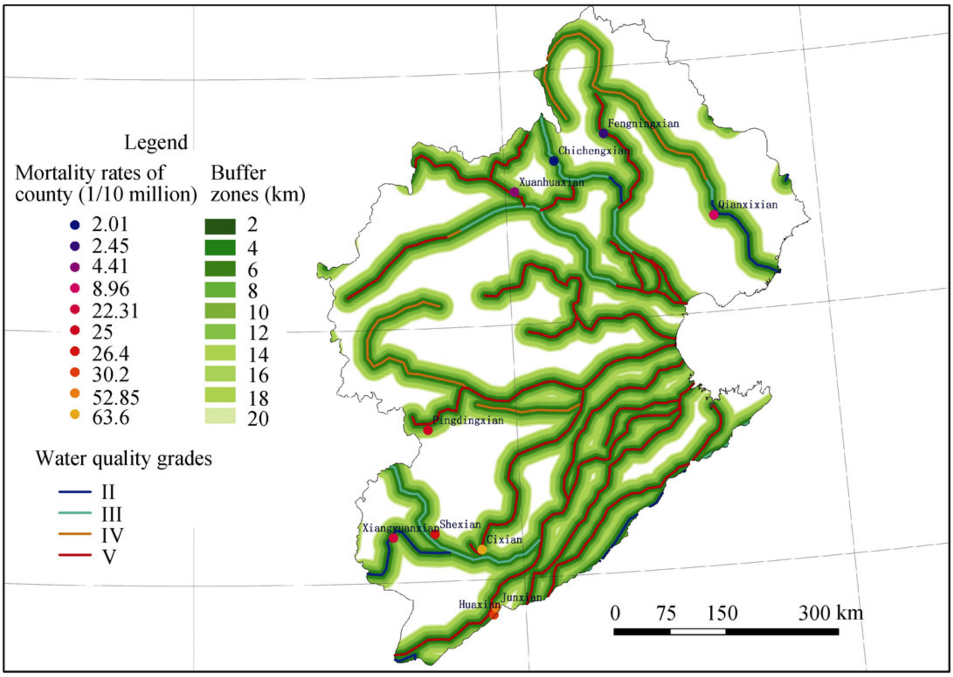

Figure 2 Water quality grade-buffer distance grouping model in the Haihe River Basin

China using the grouping method based on buffer distance from rivers and lakes at 2 km intervals for each buffer zone; 119 of 213 sampling sites satisfied the grouping conditions. The remaining 94 Sampling sites with distance to rivers and lakes exceeding 20 km were excluded from the analysis. Results indicated differences between urban and rural drinking water sources. Urban residents primarily used treated drinking water, while rural residents used untreated water as the primary source of drinking water. A 2006 survey showed people drinking untreated water represented 83.92% of the rural residents. Among the 119 sampling sites selected within the buffer zones, 72 urban sampling sites did not meet the requirement that individuals residing in the sampling sites used untreated river water or groundwater as their drinking water. Therefore, these 72 sampling sites were excluded. A total of 47 rural sampling sites met the requirements (Figure 3). These 47 sampling sites represented 22.07% of the total, however, this region represented 32.26% of the total esophageal cancer deaths nationwide. The mean esophageal cancer mortality rate for the 47 sampling sites was 12.72 in 1/10 million deaths, much higher than the national average (8.70 in 1/10 million deaths) calculated for all sampling sites.

We spatially located esophageal cancer mortality sampling sites in 10 buffer zones (Figure 3). The increased distance from rivers showed a mean decline in the esophageal cancer mortality rate (Figure 4). The X coordinate represents the buffer distance from rivers and lakes, while Y represents the mean value of esophageal cancer mortality (in 1/10 million deaths) in each group. Results showed the increase in buffer distance resulted in a decreased trend in esophageal cancer mortality. A total of 80.4% of the esophageal cancer deaths among the 47 sampling sites were distributed in the five buffer zones close to rivers and lakes, while 19.6% were in the five buffer zones further away from rivers and lakes.

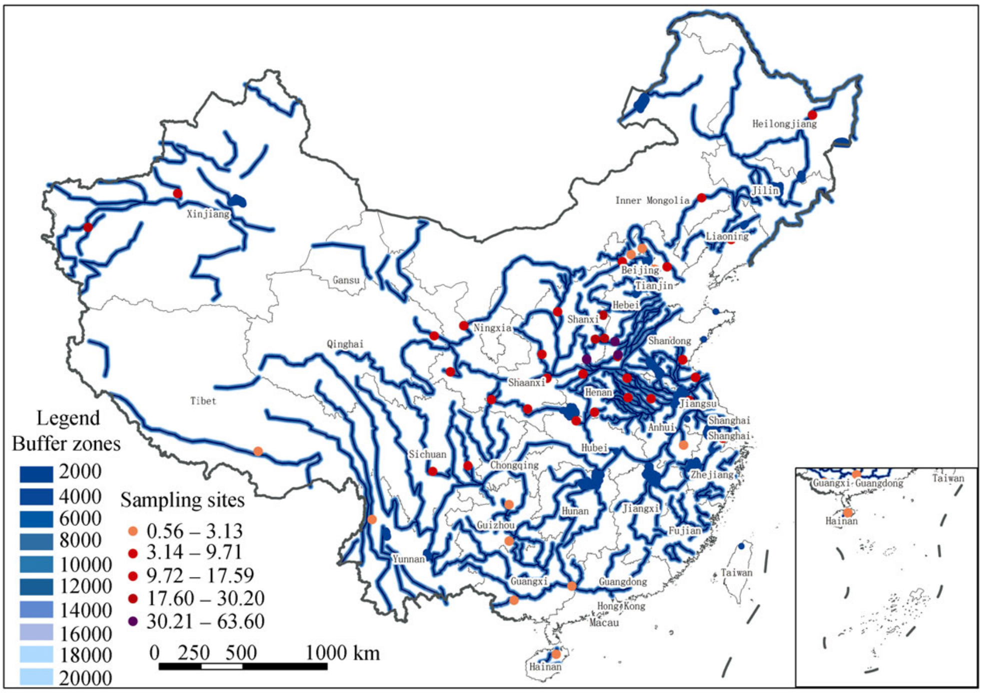

Figure 3 Sampling site distribution for esophageal cancer mortality survey in river and lake buffer zones

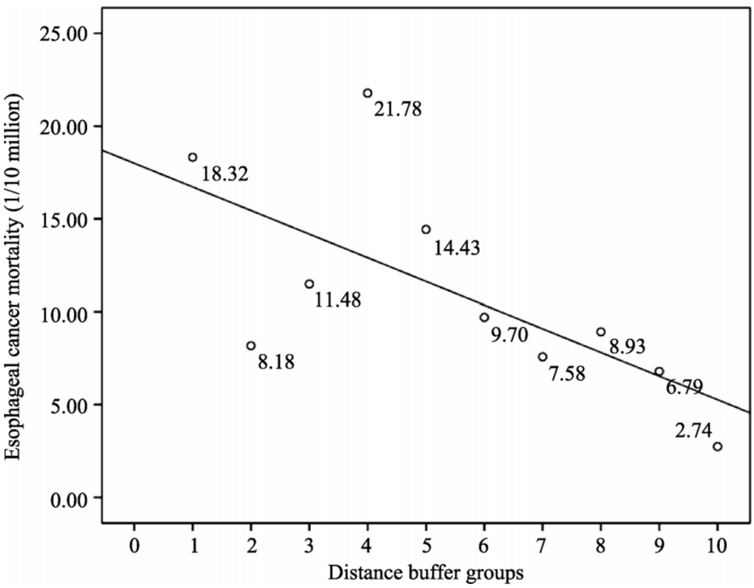

Figure 4 Correlation coefficients between esophageal cancer mortality (Y-axis) and distance from rivers and lakes (X-axis)

We used Spearman's and Kendall τ rank correlation analyses to determine if a significant correlation in esophageal cancer mortality and distance from rivers and lakes could be detected throughout the sample sites.

Table 1 Spearman's and Kendall τ rank correlation coefficient results: distance from rivers and lakes and esophageal cancer mortality

Variable 1	Variable 2	Correlation statistic analysis result			
		Spearman (r)	P	Kendall (r)	P
Esophageal cancer mortality	Distance	–0.721*	0.019	–0.600*	0.016

Note: * There is a significant correlation at the 0.05 significance test range

The results showed a significant negative correlation between esophageal cancer mortality and distance from rivers and lakes (Spearman's r = –0.721, $P < 0.05$; Kendall τ = –0.600, $P < 0.05$) (Table 1). The results indicated that when infiltration resistance and distance costs were assumed, the first hypothesis was supported. The shorter the distance of sampling sites was from polluted rivers and lakes, the higher the number of esophageal cancer deaths, and vice versa.

3.2 Correlation between esophageal cancer mortality and water quality grade of rivers and lakes

The nearest neighbor function was used to assign the 47 esophageal cancer mortality sampling sites to the nearest river or lake. We subsequently obtained five sets of river and lake water quality grades (I-V), and esophageal cancer mortality (in 1/10 million deaths) data groups. Results showed increased water pollution in rivers and lakes resulted in a rise in mean esophageal cancer mortality cases, from 9.47 at Grade I to 15.76 at Grade V (Figure 5).

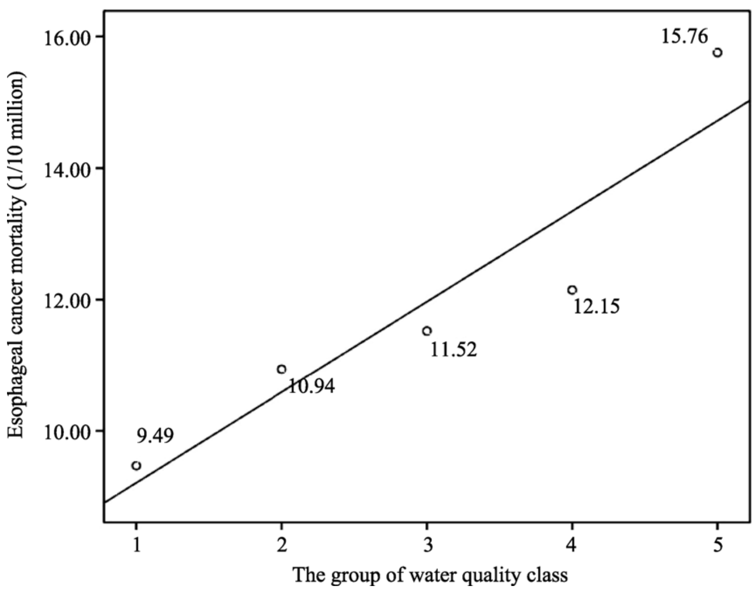

Figure 5 Correlation coefficients between esophageal cancer mortality (Y-axis) and water quality class in rivers and lakes (X-axis)

The X coordinate shows water quality grades of rivers and lakes, and the Y coordinate indicates mean esophageal cancer mortality values from sampling sites (Figure 5). Deterioration of river and lake water quality demonstrated an increasing esophageal cancer mortality rate trend. Grade V water quality areas, where water pollution was most serious, exhibited the highest esophageal cancer mortality, and represented 42.17% of the total esophageal cancer deaths among the 47 sampling sites.

Table 2 Spearman's and Kendall τ rank correlation coefficient results: water quality classes and esophageal cancer mortality

Variable 1	Variable 2	Correlation statistic analysis result			
		Spearman (r)	P	Kendall (r)	P
Esophageal cancer mortality	Water quality class	1.000**	0.000	1.000**	0.014

* There is a significant correlation at the 0.05 significance test range

Results showed a significant positive correlation between esophageal cancer mortality and water quality grades (Spearman's r = 1.000, $P < 0.001$; Kendall τ = 1.000, $P < 0.05$) (Table 2). Our results also supported our second hypothesis. River and lake water quality grades (I-V), i.e. indicative of pollution levels, suggested a significant effect on esophageal cancer mortality.

The results of correlation analyses based on the two grouping approaches verified the hypotheses proposed in this paper. A significant positive correlation between esophageal cancer mortality and water quality grades, and a significant negative correlation between esophageal cancer mortality, and distance from rivers and lakes were supported. The correlation coefficient values indicated a higher correlation between esophageal cancer mortality and water quality grade, than with buffer distance from rivers and lakes. Therefore, the results of our study provided compelling evidence that river and lake water pollution plays a leading role in esophageal cancer mortality.

4 Discussion

Previous studies on the relationship between esophageal cancer and the environment reported that water pollution was associated with esophageal cancer mortality (Dissanayake and Rohana, 2009; Meri *et al*., 1997; Han *et al*., 1997; Zhao *et al*., 2005), congruent with the results of the present study. However, these studies were scattered in different parts of the region with a high incidence of esophageal cancer. Moreover, the environmental contaminant indicators selected for the studies were varied, such as pollution index and nitrosamines (Sabo-Attwood *et al*., 2006; Liu *et al*., 2010). Research methods also differed, including laboratory analyses that examined the influence of carcinogenic substances on the human body's internal environment, epidemiological investigations, and comparative analyses of case studies, among other approaches. We adopted SEPA/MEP standard water quality grades for China's major rivers and lakes, and used the distance from rivers and lakes as a unified and comparable indicator to explore the relationship between water pollution and esophageal cancer at a national scale. By combining statistical and spatial analyses, the influence of water pollution on esophageal cancer mortality was objectively analyzed.

We defined two basic artificial research units as a result of this study. Rivers, lakes, water systems, drainage basins, and other natural geographic units were basic water pollution environmental research units; whereas surveys and statistical sampling that estimated esophageal cancer mortality rates delimited an administrative region, which determined basic administrative research units. In most cases, these unit types did not correspond. Neighborhood function, buffer zone, and other spatial analyses were employed to achieve enhanced correspondence between geographic and administrative units, with increased mastery of the spatial relationship between water pollution and esophageal cancer mortality. Delimiting a geographic research unit served to overcome the limitations of only addressing risk factors for malignant tumors using a basic administrative research branch.

We established buffer zones to determine the presence of a pollutant dispersion distance threshold between sampling sites, and rivers and lakes. We found esophageal cancer mortality at sampling sites in five buffer zones closer and five buffer zones further away from rivers and lakes showed a respective 80.4% and 19.6% of the total among the 47 sampling sites. A distance threshold clearly existed in the approximate 10 km.

The primary purpose of this paper was the discussion of research methods, and not water quality indicators as a means to identify and prevent disease. We provided two general hypotheses to test the influence and distance threshold of groundwater pollution by rivers and lakes in this study. Quantization groundwater quality, river/lake pollution, and distance threshold still require in-depth discussions.

5 Conclusions

The main results and conclusions of this study are as follows:

(1) A significant negative correlation was detected between esophageal cancer mortality and buffer distance from rivers and lakes at the sampling sites within the 20 km distance threshold, which was an analytical result of grouping according to buffer distance. Spearman's and Kendall τ rank correlation coefficients were r = –0.721 and r = –0.600, respectively, $P < 0.05$. The esophageal cancer mortality at sampling sites in five buffer zones closer and five buffer zones further away from rivers and lakes showed a respective 80.4% and 19.6% of the total among the 47 sampling sites. Therefore, within the distance threshold (20 km), the resident distance from the polluted water sources indicated an effect on esophageal cancer mortality among residents. Due to infiltration resistance limitations, and distance costs for people fetching drinking water from water sources, the closer the water source (lower buffer distance), the higher esophageal cancer deaths; alternatively, the greater the distance to water sources (greater buffer distance), the lower the number of esophageal cancer deaths.

(2) A significant positive correlation was determined between esophageal cancer mortality and water quality grades at the 47 sampling sites that satisfied the study criteria. Spearman's and Kendall τ rank correlation coefficients both exhibited r = 1.000 with respective $P <$ 0.001 and $P <$ 0.0.05. In the areas with water quality grades I to V, esophageal cancer mortality in Grade V water sampling sites alone was responsible for 42.17% of the total esophageal cancer deaths. Results showed areas with water pollution Grade V were also areas with the highest esophageal cancer mortality. Therefore, our study clearly indicated water pollution levels affected esophageal cancer mortality.

(3) Correlation coefficient value comparisons demonstrated that esophageal cancer mor-

tality rates exhibited higher correlations with water quality grades than with distance from rivers and lakes. The effect of water quality grades on esophageal cancer mortality was greater than distance from rivers and lakes. However, water quality grades, i.e. water pollution and river/lake distance were two leading factors in affecting esophageal cancer mortality.

We identified significant correlations affecting esophageal cancer mortality in China: (i) esophageal cancer mortality and buffer distance from rivers and lakes; and (ii) esophageal cancer mortality and water quality grade values. The results clearly indicated that water pollution is a risk factor for esophageal cancer mortality in China. Environmental management must review water pollution, and integrate these health risk data into management plans to improve and sustain environmental and human health. Water quality must be elevated to acceptable levels in contaminated areas, and subsequently maintained at suitable standards to ensure the health of residents living in these areas will not be threatened in the future.

References

Baudouin C, Charveron M, Tarroux R *et al*., 2002. Environmental pollutants and skin cancer. *Cell Biology and Toxicology*, 18(5): 341–348.

Brownstein J S, Rosen H, Purdy D *et al*., 2002. Spatial analysis of West Nile virus: Rapid risk assessment of an introduced vector-borne zoonosis. *Vector-Borne and Zoonotic Diseases*, 2(3): 157–164.

Chang Yuanxun, 2006. The effect of environmental pollution to human health. *Chinese General Practice*, 9(13): 1080–1081. (in Chinese)

David C W, Lance A W, Wendy C *et al*., 2012. Spatial–temporal analysis of non-Hodgkin lymphoma risk using multiple residential locations. *Spatial and Spatio-temporal Epidemiology*, 3(2): 163–171.

Dissanayake C B, Rohana C, 2009. Introduction to Medical Geology. Berlin: Springer, 139–155.

Farhad I, Paolo B, Jian Songren *et al*., 2009. High-temperature beverages and foods and esophageal cancer risk: A systematic review. *Int. J. Cancer*, 125(3): 491–524.

Gatton M L, Kay B H, Ryan P A, 2005. Environmental predictors of Ross River virus disease outbreaks in Queensland, Australia. *Am. J. Trop. Med. Hyg*., 72(6): 792–799.

Han Cunzhi, Jing Jiexian, Zhao Xianwen *et al*., 1997. Relationship between drinking water, vegetables and cancer death in the high incidence area of digestive tract cancer. *Chinese Journal of Cancer Research*, 9(2): 96–99.

Han Jianying, Xu Zhixiang, Xing Haiping *et al*., 2007. A historical cohort study on the effect of drinking water improvement to the mortality of esophageal carcinoma among Linzhou residents. *Chin. J. Epidemiol.*, 28(5): 515–516. (in Chinese)

Hu Junming, Yu Xiaoyi, Yuan Ren, 2009. Study and reflection on relation between environmental pollution and human health. *Environmental Protection*, (10): 81–83. (in Chinese)

Huang Chengmin, He Yurong, Feng Zidao, 2002. Study on soil characteristics of high-mortality area of esophageal cancer in Three Gorge Dam Region. *J. Environ. Health*, 19(1): 32–34. (in Chinese)

Hubbard A, Liang S, Maszle D *et al*., 2002. Estimating the distribution of worm burden and egg excretion of schistosoma japonicum by risk group in Sichuan Province. *China Parasitol*., 125: 221–231.

Jacob J O, Brian J S, Hoon K, 2008. Joint spatio-temporal modeling of low incidence cancers sharing common risk factors. *Journal of Data Science*, 6: 105–123.

James K H, 2004. Effects of disease type and latency on the value of mortality risk. *The Journal of Risk and Uncertainty*, 28(1): 73–95.

James T H, 1999. Exercising property rights to pollute: Do cancer risks and politics affect plant emission reductions? *Journal of Risk and Uncertainty*, 18(2): 105–124.

Jiang Chengsheng, Wang Jinfeng, Cao Zhidong, 2009. A review of geo-spatial sampling theory. *Acta Geographica Sinica*, 64(3): 368–380. (in Chinese)

Kate E J, Nikkita G P, Marc A L *et al*., 2008. Global trends in emerging infectious diseases. *Nature*, 451: 990–994.

Kenneth M B, William C S, Mark E H, 1987. Relative cancer risks of chemical contaminants in the Great Lakes. *Environmental Management*, 11(4): 495–505.

Kulldorff M, 2005. Syndromic surveillance without denominator data: the space-time permutation scan statistic for disease outbreak detection. *PloS Medicine*, 2: 216–224.

Lei Yan, Luan Rongsheng, Zhou Chao *et al*., 2006. A case control study on the effect of lifestyle on esophageal cancer in a rural county of China. *Modern Preventive Medicine*, 33(5): 755–756. (in Chinese)

Leung Y, Kwong S L, 1993. An intelligent expert system shell for knowledge-based geographical information systems: 1. The tools; 2. Some applications. *International Journal of Geographical Information Systems*, 7(3): 189–199.

Li Lianfa, Wang Jinfeng, 2005. Optimal decision-making model of spatial sampling for survey of China's land with remotely sensed data. *Science in China* (*Series D*), 48(6):752–764.

Li Wei, GuoXiaolei, Fu Zhentao *et al*., 2008. Case-control study on risk factors of esophageal cancer. *Chin. J. Pubic Health*, 24(5): 517–518. (in Chinese)

Li Xinhu, Wang Jinfeng, Liao Yilan *et al*., 2006.Geological analysis for the environmental cause of human birth defects based on GIS. *Toxicological & Environmental Chemistry*, 88 (3): 551–559.

Li Zenning, Yang Huixia, Zhang Xianghong *et al*., 2006. Analysis on contamination of ochratoxin A in crops to residents in the region with high esophageal cancer and stomach cancer incidence. *Journal of Hygiene Research*, 35(6): 754–755. (in Chinese)

Liao Yilan, Wang Jinfeng, Yang Weizhong *et al*., 2012. A study on detecting multi-dimensional clusters of infectious diseases. *Journal of Geographical Sciences*, 67(4): 435–443. (in Chinese)

Liu boqi, Jiang Jingmei, Chen Zhengming *et al*., 2006. Relationship between smoking and risk of esophageal cancer in 103 areas in China: A large-scale case-control study incorporated into a nationwide survey of mortality. *National Medical Journal of China*, 86(6): 380–385. (in Chinese)

Liu Chen-Wuing, Lin Chun-Nan, Jang Cheng-Shin *et al*., 2011. Assessing nitrate contamination and its potential health risk to Kinmen residents. *Environ. Geochem. Health*, 33: 503–514.

Liu Jiyuan, Zhong Ershun, Zhuang Dafang *et al*., 2003. Development and application of national SARS disease controlling and pre-warning information system. *Modern Scientific Instruments*, (4): 10–13. (in Chinese)

Liu Ran, Yin Lihong, Pu Yuepu *et al*., 2008. Susceptibility to esophageal cancer associated with genetic and environmental factors. *J. Environ. Occup. Med*., 25(6): 522–527. (in Chinese)

Luan Jie, Meng Leiqing, Wang Yanqing *et al*, 2010. An epidemiologic study on genetic factor in esophageal cancer of Nantong. *Modern Preventive Medicine*, 37(18): 3407–3409. (in Chinese)

Manami I, Motoki I, Tetsuya O *et al*., 2006. Public awareness of risk factors for cancer among the Japanese general population: A population-based survey. *BMC Public Health*, 6(2): 1–6.

Melissa M A, Michael H, Jamison C *et al*., 2011. The association between mountaintop mining and birth defects among live births in central Appalachia, 1996–2003. *Environmental Research*, 111: 836–846.

Meri K, Eero P, Terttu V *et al*., 1997. Drinking water chlorination and cancer: A historical cohort study in Finland. *Cancer Causes and Control*, 8: 192–200.

Mohammadreza M, Rory W, Damien J *et al*., 2011. The spatial distribution of esophageal and gastric cancer in Caspian region of Iran: An ecological analysis of diet and socio-economic influences. *International Journal of Health Geographics*, 10: 13–23.

Nobuaki S, Yogendra S, Hideto S, 1996. Effect of ethanol on esophageal cell proliferation and the development of N-methyl-N′-nitro-N-nitrosoguanidine induced-esophageal carcinoma in shrews. *Journal of Cancer Research and Clinical Oncology*, 122(10): 613–618.

Nuria A, Rebeca R, Marina P *et al*., 2007. Oesophageal cancer mortality in Spain: A spatial analysis. *BMC Cancer*, 7: 3.

Pan Kejie, 2006. Research progress on risk factors of esophageal cancer. *Anhui J Prev. Med*., 12(6): 411–414. (in

Chinese)

Peng Xian'e, Zhou Zijin, Shi Xiyao *et al*., 2005. Case-control study on risk factors of esophageal cancer in Anxi County. *Chin. J. Public Health*, 21(1): 10–12. (in Chinese)

Rogers D J, Randolph S E, 2003. Studying the global distribution of infectious diseases using GIS and RS. *Nature Rev.*: *Microb*., 1: 231–237.

Sabo-Attwood T, Ramos-Nino M, Mossman B T, 2006. Environmental carcinogenesis. *Oncology*, 233–243.

Shen Caihe, Liu Cunfu, Zhou Aiguo *et al*., 2002. Study of correlation for the NO_3 contamination of drinking water and for the rate of disease and death of esophagus cancer of Linzhou and Anyang in Henan Province. *Geological Science and Technology Information*, 22(1): 91–94. (in Chinese)

Soliman A S, Wang X, Stanley J D *et al*., 2006. Geographical clustering of pancreatic cancers in the Northeast Nile Delta Region of Egypt. *Environ. Contam. Toxicol*., 51: 142–148.

Song Yuzhi, Wang Jinqi, Xie Xuejian *et al*., 2008. Water environmental pollution and its impact on human health in China. *Journal of Anhui Agri. Sci*., 36(27): 11974–11976. (in Chinese)

Tong Jandong, Ding Yanbin, Yan Zhigang *et al*., 2007. The study on risk factor on gastric cancer and esophageal cancer in Yangzhou district. *Actauniversitatis Medicinalis Nanjing* (*Natural Science*), 27(6): 641–644. (in Chinese)

Van Grinsven H J M, Mary H W, Nigel B *et al*., 2006. Does the evidence about health risks associated with nitrate ingestion warrant an increase of the nitrate standard for drinking water? *Environmental Health*: *A Global Access Science Source*, 26(5): 1–6.

Wang Jinfeng *et al*., 2006. Spatial Analysis. Beijing: Science Press, 99–116. (in Chinese)

Wang Jinfeng, McMichael A J, Meng Bin *et al*., 2006.Spatial dynamics of an epidemic of severe acute respiratory syndrome in an urban area. *Bulletin of the World Health Organization*, 84(12): 965–968.

Wang Jinying, Liu Guoyao, 2006. A study of status quo and countermeasures for harm of water pollution to people's health. *Environmental Science and Technology*, 29(B08): 80–81. (in Chinese)

Wang Xiumei, Jie Ensi, Ma Yanqing *et al*., 2007. Case-control study on risk factors of esophageal cancer in Xinjiang Kazakh nationality. *China J. Public Health*, 23(6):737–738. (in Chinese)

Wei Junping, Fan Qingtang, Li Xiurong *et al*., 1999. A survey on the health condition for residents living along the Manghe River. *Journal of Environment and Health*, 16(4): 224–244. (in Chinese)

World Health Organization, 2004. World Health Report 2004: Changing history. Available from http://www.who.int/whr (assessed in July 2010).

Yang Lei, Wang Shaokang, Sun Guiju *et al*., 2009. A case-control study on the risk factors for esophageal cancer. *Tumor*, 29(3): 249–252. (in Chinese)

Yang Linsheng, Li Hairong, Li Yonghua *et al*., 2010. Progress of medical geography and environmental health studies. *Progress in Geography*, 29(1): 31–44.

Yang Yan, Yang Zhongfang, Hou Qingye *et al*., 2008. Relationship between esophageal cancer and environmental geochemistry in Yanting county, Sichuan province. *Geosicence*, 22(6): 1015–1021. (in Chinese)

Zhang Xiaogang, Wang Jianfei, 2009. Evaluation of risk factors and prevention strategies of esophageal cancer. *World Chinese Journal of Digestology*, 17(7): 677–680. (in Chinese)

Zhao Jinkou, Wu Ming, Liu Aimin *et al*., 2005. A population-based 1:1 matched case-control study on risk factors for esophageal cancer in a high cancer incidence area of Jiangsu Province, China: Preliminary results. *Chinese Journal of Prevention and Control of Chronic Non-communicable Diseases*, 13(1): 17–19. (in Chinese)

Zhen Defeng, Shi Yanguang, Cui Shuai, 2008. Health risk assessment of contaminants in source of drinking water. *Water Resources and Power*, 26(6): 48–57. (in Chinese)

Zhou Yingzhi, Li Hao, Zhao Deli *et al*., 2006. Multinomial logistic regression for influence factors of esophageal lesions. *Chin. J. Public Health*, 22(12): 1437–1438. (in Chinese)

Zhu Lewei, He Jianxing, Tan Jiaju *et al*., 2010. Comparative study on the mutagenicity of drinking water in high and low risk areas for esophageal cancer in southern China. *China Prac. Med*., 5(30): 15–17. (in Chinese)