RESEARCH ARTICLE

Anisotropic Patterns of Liver Cancer Prevalence in Guangxi in Southwest China: Is Local Climate a Contributing Factor?

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Abstract

Geographic information system (GIS) technology has useful applications for epidemiology, enabling the detection of spatial patterns of disease dispersion and locating geographic areas at increased risk. In this study, we applied GIS technology to characterize the spatial pattern of mortality due to liver cancer in the autonomous region of Guangxi Zhuang in southwest China. A database with liver cancer mortality data for 1971-1973, 1990-1992, and 2004-2005, including geographic locations and climate conditions, was constructed, and the appropriate associations were investigated. It was found that the regions with the highest mortality rates were central Guangxi with Guigang City at the center, and southwest Guangxi centered in Fusui County. Regions with the lowest mortality rates were eastern Guangxi with Pingnan County at the center, and northern Guangxi centered in Sanjiang and Rongshui counties. Regarding climate conditions, in the 1990s the mortality rate of liver cancer positively correlated with average temperature and average minimum temperature, and negatively correlated with average precipitation. In 2004 through 2005, mortality due to liver cancer positively correlated with the average minimum temperature. Regions of high mortality had lower average humidity and higher average barometric pressure than did regions of low mortality. Our results provide information to benefit development of a regional liver cancer prevention program in Guangxi, and provide important information and a reference for exploring causes of liver cancer.

Keywords: Liver cancer - spatial pattern - climate - geographic information system (GIS)

Asian Pac J Cancer Prev, **16 (8)**, 3579-3586

Introduction

The autonomous region of Guangxi Zhuang (Guangxi) has one of the highest incidences of liver cancer in China. While the third national retrospective sampling survey conducted in 2004-2005 across China reported that mortality due to liver cancer was 37.55 and 14.45 per 100 000 for males and females, respectively (Chen, 2011), a retrospective sampling survey performed in Guangxi for the same period found that mortality was 55.94 and 14.53 per 100 000. Furthermore, in Guangxi liver cancer was the first cause of death among malignant tumors, accounting for 36.01% and 18.88% for men and women, respectively, of all tumor-related deaths (Wei et al., 2014).

Guangxi comprises an area of 236, 700 km^2, and the incidence of liver cancer is greater in some regions than others. Data drawn from cases of liver cancer in hospitals revealed that the cities and counties with higher incidences of liver cancer were mainly around the middle of the Yu River and Hongshui River, as well as in southwest Guangxi where mortality was higher than twice the average for all of Guangxi (Huang et al., 2000; Tang et al., 2009). Generally, hepatitis B virus infection, aflatoxin contamination, and drinking water pollution are the major risk factors for liver cancer occurring in China (Ruan, 1997; Ming et al., 2002; Zhu, 2012; Chang, 2014). Because there has been a significant increase in the incidence of primary liver cancer (PLC) in regions where water from cyanobacterial blooming reservoirs was used for human consumption (Svircev et al., 2013), and because climatic and crop storage conditions are frequently conducive to fungal growth and mycotoxin production (Shephard, 2008), it is probable that environmental factors, especially climatic factors, are related to the occurrence of liver cancer reflected by differences in geographic distribution in Guangxi.

Some studies have shown that environmental factors account for 80% to 90% of cancer occurrence (Wu, 1982). Wu found that esophageal cancer in China has a significant regional aggregation, and its mortality is related to precipitation, water-heat index, temperature, wind speed, vegetation index, and geographic elevation (Wu et al., 2008). Studies of the association between climatic factors and liver cancer conducted in China have indicated that liver cancer mortality positively correlates with temperature, rainfall, humidity and evaporation (Qin

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et al., 2003; Lv, 2004; Li et al., 2005).

The complexity of spatial geographic and climatic data with geographic coordinates makes analysis using traditional epidemiological methods very difficult. The development of geographic information system (GIS) technology has enabled the processing and analysis of spatial data and the determination of geographic patterns in disease prevalence. GIS was first used in the early 1960s in the Canadian forest management system. In the last 20 years, its data processing and spatial analysis techniques have been applied in public health and epidemiological research. For the latter, GIS was first used to study vector-borne diseases. More currently, studies that utilize GIS technology have focused on communicable diseases, including Lyme disease, malaria, schistosomiasis, severe acute respiratory syndrome (SARS), and acquired immunodeficiency syndrome (AIDS) (Graves, 2008). GIS is also widely used to study the geographic patterns and etiology of non-communicable diseases such as asthma, cardiovascular diseases, diabetes, and obesity, and even to study health service planning, public health, and health technologies and tools (Lyseen et al., 2014).

The present study used GIS technology to perform spatial analysis of liver cancer mortality data for the entire population of Guangxi. Thus we were able to interactively and visually describe the spatial distribution characteristics of liver cancer in Guangxi. In addition, climate data were imported to analyze the climatic factors affecting liver cancer mortality.

Materials and Methods

The autonomous region of Guangxi is located in southwest China and has a subtropical climate. Summers are generally long and hot. The average annual temperature is 17 to 23°C, while average annual precipitation is 1250 to 1750 mm. The total population was approximately 51.59 million in 2010, composed primarily of ethnic Han and Zhuang (62% and 34% of the population, respectively). Guangxi's 2011 nominal GDP was ~1171.4 billion yuan (USD 185.9 billion) and ranked 18th in China. It is partly mountainous and divided into 14 prefecture-level cities, 56 counties, 34 districts, 12 ethnic autonomous counties, and 7 county-level cities. All the counties, districts, and county-level cities are coded with numbers from 1 to 109. (Numbers used to label the maps of Figures 1-3 correspond to the numbers in Table 1).

The mortality data for liver cancer in Guangxi were obtained from cause-of-death surveys for the years 1971-1973, 1990-1992, and 2004-2005, organized by the Ministry of Health of the People's Republic of China and the National Cancer Prevention Office (http://cancernet.cicams.ac.cn). These surveys aimed to find the major diseases that threaten the health of the population. The sampling method and coverage of the three surveys in Guangxi were performed as previously described (Wei et al., 2014). In rural southwest China, liver cancer is almost incurable, and therefore mortality due to liver cancer is nearly equal to the incidence. In this study, mortality rates were used rather than incidence, because data on cancer incidence in Guangxi is incomplete or unreliable.

Climate data was provided by the Thematic Database for Human-Earth System, an information technology project by the Chinese Academy of Science (www.data.ac.cn). Measurements were conducted at climate monitoring sites in Guangxi. Measurements used in the present study consisted of averages for annual mean temperature (°C), maximum temperature (°C), minimum temperature (°C), humidity (%), precipitation (mm), sunshine (W/m^2) and barometric pressure (hPa), taken from 1978 to 2005 in counties, districts, and county-level cities which conducted cause-of-death surveys (10 sampled counties in the 1990s and 9 in the 2000s).

Spatial data were imported into the software suite ArcGIS 9.3 to generate an electronic (digital) map of Guangxi. Data regarding liver cancer mortality and environmental factors for the sampled counties in Guangxi were converted into database files (.dbf), after which the corresponding .dbf files were imported through the joint menu of the Arc GIS 9.3 geographic information software as the attribute data of the map. With the spatial and attribute data integrated, the GIS for liver cancer mortality in Guangxi was established, the county boundary map layer being associated with the databases for liver cancer deaths and environmental factors, according to the names of the counties.

A map was thus generated, displaying the geographic distribution of deaths due to liver cancer in Guangxi. Using Moran's I and Getis' coefficient, the log value of the liver cancer mortality rate was analyzed to assess its spatial autocorrelation across a set of locations. The value of Moran's I range from -1 to +1, where a significant negative value indicates that nearby locations tend to have different values (i.e., spatial dispersion); an insignificant value indicates that the spatial distribution of the deaths is random, and a significant positive value indicates that nearby locations tend to have similar values (i.e. spatial clustering). Positive and significant values of Getis' coefficient suggest a cluster of high values, whereas negative and significant values suggest a cluster of low values. The Z-score is the test statistic for Moran's I and Getis' coefficient; when Z is positively or negatively greater than some specified level of significance, then we say that a positive or negative spatial association obtains.

Kriging spatially interpolation is a method to predict unknown values from data observed at known locations. In this study, the liver cancer mortality data of each county was applied to plot the interpolation map, that is, to predict changes in geographic distribution of liver cancer mortality throughout Guangxi. Because the 1990-1992 and the 2004-2005 surveys are sampling surveys for causes of death, the numbers of sampling points in all cities and counties were too low, and the spatial distribution was discrete. The missing spatial data for liver cancer mortality limited the plotting of the interpolation map for the corresponding years. Therefore, this study only plotted the interpolation map for liver cancer mortality in Guangxi from 1971-1973.

Potential associations between liver cancer mortality and the climate variables at the corresponding monitoring sites were analyzed. Because the data for liver cancer mortality and some climate variables were not normally distributed, their associations were analyzed using Spearman's rank correlation. Climatic factors that showed correlations with liver cancer mortality were processed by univariate regression analysis and equation curve fitting, with the logarithm of liver cancer mortality serving as the dependent variable and the related climatic factors serving as independent variables. Equation curve fitting

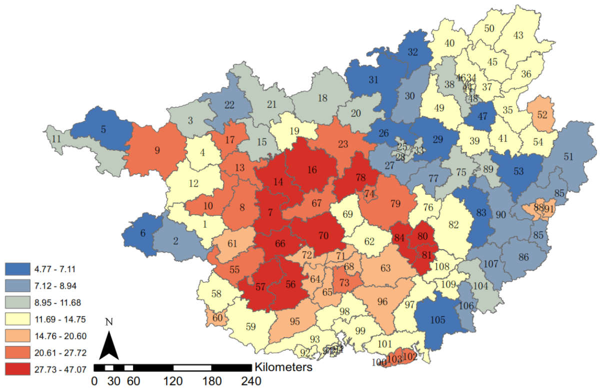

Figure 1. Thematic Map for the Distribution of Liver Cancer Mortality (1/100 000) in Guangxi from 1971-1973. All the county/district/county-level cities are coded with numbers from 1 to 109, corresponding to those in Table 1

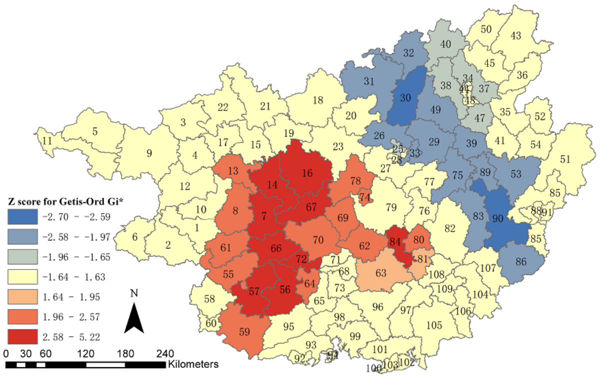

Figure 2. Z-value Distribution of Regional Getis Analysis for Liver Cancer Mortality in Guangxi from 1971-1973. All the county/district/county-level cities are coded with numbers from 1 to 109, corresponding to those in Table 1.

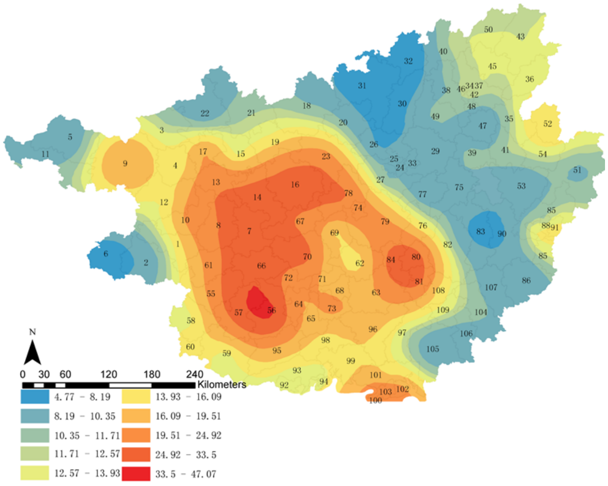

Figure 3. Kriging Interpolation Map of Liver Cancer Mortality (1/100 000) in Guangxi in 1971-1973. All the county/district/county-level cities are coded with numbers from 1 to 109, corresponding to those in Table 1.

Table 1. Results of Regional Getis Analysis for the Liver Cancer Mortality Rate of Guangxi from 1971-1973

Prefecture-level Cities	County/District/ county-level cities (Code*)	Z (Gi)
Baise City	Debao County (1)	0.47
	Jingxi County (2)	-0.51
	Leye County (3)	0.31
	Lingyun County (4)	1.06
	Longlin Nationality Autonomous County (5)	-0.11
	Napo County (6)	-1.49
	Pingguo County (7)	4.39
	Tiandong County (8)	2.17
	Tianlin County (9)	-0.61
	Tianyang County (10)	1.16
	Xilin County (11)	-0.11
	Youjiang District (12)	0.64
Hechi City	Bama Yao Autonomous County (13)	2.31
	Dahua Yao Autonomous County (14)	2.7
	Donglan County (15)	0.79
	Duan Yao Autonomous County (16)	3.06
	Fengshan County (17)	-0.10
	HuanjiangMaonan Autonomous County (18)	-0.99
	Jinchengjiang District (19)	1.18
	LuochengMulao Autonomous County (20)	-1.31
	Nandan County (21)	-1.34
	Tiane County (22)	-0.68
	Yizhou City (23)	0.38
Liuzhou City	Chengzhong District (24)	-1.26
	Liubei District (25)	-1.90
	Liucheng County (26)	-2.23
	Liujiang District (27)	-0.78
	Liunan District (28)	-1.54
	Luzhai County (29)	-2.49
	Rongan County (30)	-2.70
	Rongshui Miao Autonomous County (31)	-2.56
	Sanjiang Dong Autonomous County (32)	-1.98
	Yufeng District (33)	-2.21
Guilin City	Diecai District (34)	-0.81
	Gongcheng Yao Autonomous County (35)	-1.01
	Guanyang County (36)	-0.91
	Lingchuan County (37)	-1.85
	Lingui County (38)	-1.95
	Lipu County (39)	-2.20
	Longsheng Nationality Autonomous County (40)	-1.83
	Pingle County (41)	-1.60
	Qixing District (42)	-1.09
	Quangzhou County (43)	-0.81
	Xiangshan District (44)	-1.18
	Xingan County (45)	-1.00
	Xiufeng District (46)	-1.16
	Yangshuo County (47)	-1.70
	Yanshan District (48)	-1.61
	Yongfu County (49)	-2.06
	Ziyuan County (50)	-0.81
Hezhou City	Babu District (51)	-1.64
	Fuchuan Yao Autonomous County (52)	-0.08
	Zhaoping County (53)	-2.11
	Zhongshan County (54)	-1.03
Chongzuo City		
	Daxin County (55)	1.97
	Fusui County (56)	3.46
	Jiangzhou District (57)	3.54

	Longzhou County (58)	1.05
	Ningming County (59)	2.08
	Pingxiang City (60)	-0.44
	Tiandeng County (61)	2.11
Nanning City	Binyang County (62)	2.04
	Heng County (63)	1.83
	Jiangnan District (64)	2.25
	Liangqing District (65)	0.82
	Longan County (66)	5.22
	Mashan County (67)	3.97
	Qingxiu District (68)	0.86
	Shanglin County (69)	2.15
	Wuming County (70)	2.55
	Xingning District (71)	1.27
	Xixiangtang District (72)	3.79
	Yongning District (73)	0.79
Laibin City	Heshan City (74)	2.2
	Jinxiu Yao Autonomous County (75)	-2.04
	Wuxuan County (76)	1.12
	Xiangzhou County (77)	-1.16
	Xincheng County (78)	2.27
	Xingbin District (79)	1.06
Guigang City	Gangbei District (80)	2.5
	Gangnan District (81)	1.64
	Guiping City (82)	0.04
	Pingnan County (83)	-2.00
	Qintang District (84)	2.69
Wuzhou City		
	Cangwu County (85)	-1.54
	Cenxi City (86)	-1.97
	Changzhou District (87)	-0.13
	Dieshan District (88)	-0.13
	Mengshan County (89)	-2.09
	Teng County (90)	-2.66
	Wanxiu District (91)	-0.13
Fangchenggang City		
	Dongxing City (92)	-0.51
	Fangcheng District (93)	-0.63
	Gangkou District (94)	-0.51
	Shangsi County (95)	1.47
Qinzhou City		
	Lingshan County (96)	0.16
	Pubei County (97)	0.11
	Qinbei District (98)	0.4
	Qinnan District (99)	-0.40
Beihai City	Haicheng District (100)	1.12
	Hepu County (101)	0.53
	Teishangang District (102)	1.12
	Yinhai District (103)	1.53
Yulin City	Beiliu City (104)	-1.30
	Bobai County (105)	-1.34
	Luchuan County (106)	-1.37
	Rong County (107)	-1.14
	Xingye County (108)	0.08
	Yuzhou District (109)	-1.41

* Note: a. Guangxi is divided into 14 prefecture-level cities, 56 counties, 34 districts, 12 ethnic autonomous counties, and 7 county-level cities. All the counties, districts, and county-level cities are coded with numbers from 1 to 109. Numbers used to label the maps of Figure 1-3 correspond to the number in Table 1. b. The Z (Gi) is the test statistics for Moran's I and Getis' coefficient. A region with Z (Gi) values >1.96 is an agglomeration with a statistically significant high mortality rate due to liver cancer in this area. A regions with Z (Gi) value <-1.96 is an agglomeration with a statistically significant low mortality rate in this area. The Z (Gi) values of other regions ranged from -1.96 to 1.96, showing no statistically significant agglomeration of liver cancer mortality

Table 2. Spearman's Rank Correlation Analysis of Liver Cancer Mortality and Average Climatic Factors

	1990-1992 Correlation coefficient	*P*	2004-2005 Correlation coefficient	*P*
Mean temperature (°C)	0.585*	0.046	0.583	0.099
Maximum temperature (°C)	0.493	0.103	0.25	0.516
Minimum temperature (°C)	0.768**	0.004	0.717*	0.03
Humidity (%)	-0.265	0.465	-0.126	0.748
Precipitation (mm)	-0.761**	0.004	-0.150	0.7
Sunshine (W/m^2)	0.183	0.569	0.367	0.332
Barometric pressure (hPa)	0.225	0.481	0.467	0.205

*Note: *$P<0.05$; **$P<0.01$

was conducted using SPSS16.0 software. The best model was selected based on the value of the coefficient of determination, R^2.

The cities and counties included in the sampling surveys of the 1990s and early 2000s were divided into two groups based on the mean mortality. The regions with mortality twice more than the mean were considered areas of high mortality, while the others were defined as low mortality areas. Differences in climate were compared between the two groups using a t-test to further explore the correlation between the regional distribution of liver cancer and climatic conditions.

Results

Thematic maps of the distribution of liver cancer in Guangxi

A thematic map of the distribution of liver cancer mortality in the 1970s in Guangxi was created (Figure 1). The regions with high mortality rates due to liver cancer in the 1970s were mainly located in central and southwest Guangxi, namely Fusui County (47.07 per 100000), Longan County (34.45 per 100000), Wuming County (34.45 per 100000), Chongzuo County (33.00 per 100000), Guigang City (31.75 per 100000), Duan Yao Autonomous County (31.70 per 100000), Dahua Yao Autonomous County (31.70 per 100000), Xincheng County (29.39 per 100000), and Pingguo County (29.05 per 100000). The concentric circles centered in this area show a trend in decreasing liver cancer mortality from the center to the perimeter. The regions with low mortality rates included Bobai County (8.94 per 100000), Longlin Nationality Autonomous County (7.11 per 100000), Zhaoping County (6.88 per 100, 000), Luzhai County (6.54 per 100000), Pingnan County (6.46 per 100000), Liucheng County (6.33 per 100, 000), Rongshui Miao Autonomous County (6.14 per 100, 000), Napo County (6.12 per 100000), Yangshuo County (5.57 per 100000), and Sanjiang Dong Autonomous County (4.77 per 100000).

Spatial autocorrelation analysis of the distribution of liver cancer in Guangxi

The results showed a Moran's *I* coefficient of 0.45343, Z=7.496054 and *P*<0.001, indicating a positive spatial autocorrelation of liver cancer mortality in Guangxi that is statistically significant, with an aggregated distribution. The global Getis-Ord analysis for liver cancer mortality

Table 3. Regression and Equation Curve Fitting of Liver Cancer Mortality and Average Climatic Factors

	Best model	Regression equation	R^2	B	95% CI	F	*P*
1990s							
Mean temperature, °C	S-shaped curve	$y = e^{1.448-22.45/x}$	0.54	-22.450	-37.04 to -7.86	11.757	0.006
Minimum temperature, °C	Compound curve	$y = 1.308 \times 1.044^x$	0.638	1.044	1.02 to 1.07	17.587	0.002
Precipitation, mm	Logarithmic curve	$y = 6.305-0.679\ln x$	0.442	-0.679	-1.22 to -0.14	7.913	0.018
Early 2000s							
Minimum temperature, °C	Cubic curve	$y = 1.361 + 0.015x + 0.085x^2 -0.017x^3$	0.766	$0.015x$	$-0.10x$ to $0.13x$	5.458	0.049
				$0.085x^2$	$-0.06x^2$ to $0.23x^2$		
				$-0.017x^3$	$-0.05x^3$ to $0.01x^3$		

Table 4. Analysis of the Differences in Average Climatic Factors in Regions of High and Low Liver Cancer Mortality Rates

	1990-1992			2004-2005		
	High mortality	Low mortality	*P*	High mortality	Low mortality	*P*
Mean temperature (°C)	21.5	19.5	0.085	21.4	20.7	0.642
Maximum temperature (°C)	38.1	37.2	0.527	37	36.9	0.391
Minimum temperature (°C)	3.6	-0.57	0.21	2.217	0.55	0.288
Humidity (%)	77.2	78.27	0.379	76.89	78.54	0.031*
Precipitation (mm)	1134	1564	0.258	1664	1583	0.194
Sunshine (W/m^2)	1527.4	1562.3	0.596	1551.6	1447.1	0.323
Barometric pressure (hPa)	992.7	993.9	0.838	1001.5	986.3	0.006**

*Note: *$P<0.05$; **$P<0.01$

rate in Guangxi in 1971-1973 shows that G=0.010388, Z=4.790916 and P<0.001, indicating that the liver cancer mortality in Guangxi exhibited agglomeration, which was also an agglomeration with high mortality. The Getis-Ord analysis of locality was performed for liver cancer mortality in Guangxi in 1971-1973, for which the maximum and minimum values of Z were 5.22 and -2.70, respectively (Table 1).

To reveal better the trends in spatial distribution of liver cancer mortality, this study stratified the Z-value into seven groups (Figure 2). The regions with Z (G_i) values >1.96 were mainly located in central and southwest Guangxi, (corresponding to the red and light red area in Figure 2). There is an agglomeration with a statistically significant high mortality rate due to liver cancer in this area. The regions with Z (G_i) value <-1.96 were mainly located in the panhandle from northern to eastern Guangxi (the blue and light blue area in Figure 2). There is an agglomeration with a statistically significant low mortality rate in this area. The Z (G_i) values of other regions ranged from -1.96 to 1.96, showing no statistically significant agglomeration of liver cancer mortality, indicating an intermediate transition zone.

Interpolation map for the distribution of liver cancer in Guangxi

The regions with high mortality rates due to liver cancer in Guangxi were mainly located in central Guangxi, centered in Guigang City, and southwest Guangxi, centered in Fusui County (Figure 3). The regions with low mortality rates were mainly located in eastern Guangxi, centered in Pingnan County, and northern Guangxi, centered in Sanjiang and Rongshui counties.

Associations between the regional distribution of liver cancer mortality in Guangxi and climatic factors

Correlation analysis of liver cancer mortality and climatic factors: Liver cancer mortality in the 1990s positively correlated with the average annual temperature and the average annual minimum temperature, and negatively correlated with the average annual precipitation (Table 2). The liver cancer mortality in 2004-2005 positively correlated with the average annual minimum temperature.

Regression and curve fitting of liver cancer mortality and climate variables: The association between climate factors (the mean temperature, minimum temperature, precipitation in the 1990s, and minimum temperature in the early 21st century) and liver cancer mortality can be predicted using the curve models. The regression coefficients, including P-value and 95%CI of each model, are shown in Table 3.

Comparative analysis of the spatial factors of geography and climate in regions with different mortality levels: In 2004-2005, the average humidity and barometric pressure of regions with high liver cancer mortality rates differed significantly from those of regions with low mortality (Table 4). Regions of high cancer mortality rates had significantly lower average humidity and higher average barometric pressure than did regions of low mortality in these years (P<0.05).

Discussion

In this study, we applied GIS technology to characterize the spatial pattern of mortality due to liver cancer in Guangxi, China. It was found that the regions with the highest mortality rates were central Guangxi with Guigang City at the center, and southwest Guangxi centered in Fusui County. Ever since the mortality survey taken in the 1970s, southwest Guangxi has remained an area with a significantly higher incidence of liver cancer (Wei et al., 2014). In this area, on-site prevention and control of liver cancer was focused on Fusui County. Measures included monitoring the incidence of liver cancer with follow-up, primary prevention of the major risk factors associated with liver cancer (hepatitis B virus, aflatoxin, and the contamination of drinking water), and screening high-risk populations to detect the disease in the early stages followed-up with timely treatment. These comprehensive and effective prevention and control measures resulted in a stabilized incidence and even a slight decline of liver cancer in Fusui County over the past 30 years, in the case of increase in total mortality of liver cancer in Guangxi. Based on the thematic map of liver cancer mortality and the Kriging interpolation map of Guangxi produced in this study, we observed that regions with high mortality rates due to liver cancer covered nearly one-third of the geographic area of Guangxi, not only in southwest Guangxi but also in central Guangxi. To reduce the overall incidence of liver cancer, after accurately identifying areas of high incidence, prevention and control programs must be promoted over a larger area as conducted in Fusui, concentrating limited health resources in the regions that need it most to ensure the cost-effectiveness of the programs.

By comparing data drawn from different areas, the cancer distribution map based on tumor incidence revealed an increase in the incidence of cancer in some regions. However, these phenomena may be isolated events, and deserve attention and research only when statistically significant. To reduce the effects of confounding factors in the analysis of tumor spatial data when using GIS and avoid bias from the integration of environmental factors, some scholars believe that certain basic principle of data processing and a unified geocoding method must be adhered to, using particular statistical methods (Brewer, 2006; Rushton et al., 2006; Bender et al., 2012). In the present study, after plotting the thematic map to achieve visualization of the regional characteristics of the disease, spatial autocorrelation for geographic distribution was further analyzed, and the overall trend in regional distribution was evaluated using the Kriging interpolation method. The imbalance in geographic distribution of liver cancer was confirmed using spatial statistics, and two areas in central and southwest Guangxi were clearly identified as areas of high incidence.

Environmental factors that affect the distribution patterns of tumors have been analyzed using spatial GIS technology. Such an analysis can effectively reveal the exogenous risk factors for tumors to some extent and provide valuable information for the etiological study of cancers (Bellander et al., 2001; Guajardo, 2009; Beale et al., 2010; Gallagher et al., 2010; Hendryx, 2010). For example, in the Cape Cod region of Massachusetts the incidence of breast cancer was found to be 130-fold that of other regions. Using GIS technology, scientists analyzed the association between breast cancer incidence and areas with a history of pesticide application, and water quality. It was observed that the occurrence of breast cancer was closely related to environmental factors, and the residents living in areas with pesticide application were at higher risk of breast cancer (Brody et al., 2004). Cornelis et al. constructed a database of the historical use of pesticides in the Provence of Limburg, Belgium, and confirmed that GIS technology could integrate pesticide dose, fruit tree area, and residence area to fit an appropriate model of historical exposure to pesticides (Cornelis et al., 2009).

In addition to environmental pollutants, GIS technology can also assess geographic and climatic factors in the natural ecological environment and analyze their association with the incidence and mortality of cancer. This can provide a large amount of basic information and etiological clues regarding the prevention of primary cancer (Wu et al., 2008; Li et al., 2010; Su et al., 2010). Therefore, in the present study we also employed GIS technology to conduct a preliminary investigation of the correlation between liver cancer and climatic factors, based on the description of the geographic distribution of liver cancer.

In the present study we observed that liver cancer mortality positively correlated with average temperature and average minimum temperature, and negatively correlated with average annual precipitation. Previous analogous studies (Qin et al., 2003; Lv, 2004; Li et al., 2005) also found that liver cancer mortality positively correlated with temperature. Higher temperatures and wetter conditions favor growth of *Aspergillus flavus*, while cyanobacterial blooms occur earlier and last longer with increases in temperature, sunshine hours, and global radiation (Dziallas, 2011; Astoreca et al., 2012; Giorni et al., 2012; Zhang et al., 2012; Paerl, 2013). *Aspergillus flavus* and cyanobacteria produce aflatoxin and cyanotoxins, respectively, both of which are harmful to humans, and are recognized environmental risk factors of liver cancer (Ruan, 1997; Ming et al., 2002).

In this study, although liver cancer mortality negatively correlated with average annual precipitation, and regions of high mortality had lower average humidity than did regions of low mortality, it remains that all of the sample points are warm and humid with annual precipitation higher than 1000.00mm and average humidity greater than 75%.Differences in mortality may be due to reliance on corn as the staple food in central and southwest Guangxi, and because corn is more easily contaminated by aflatoxin than rice (Gao et al., 2011; Firdous et al., 2014). This undoubtedly increases the risk of aflatoxin intake by residents in these two areas.

Based on the above analysis, we developed suitable regression models for predicting liver cancer mortality outside the sample points, according to the corresponding temperature and precipitation in the 1990s and early 21st century. However, an analysis of the climatic risk factors for liver cancer was made difficult by the lack of liver cancer incidence data for each year and the limited number of sampling points in the surveys of mortality, as well as the climate monitoring points that failed to achieve correspondence. This may explain inconsistencies in the association between climatic factors and liver cancer mortality for different periods. Moreover, the occurrence of liver cancer results from a complex interaction of biological factors, life style, diet, and environmental factors, and to clarify only the influence of climate factors on liver cancer is insufficient. The methodological limitations of the present study did not significantly influence our findings, which are in accord with previous studies, and which proceed logically from the facts known regarding the biological and environmental risk factors of liver cancer. This study provides some important information and climatic reference data for exploring alternate causes of liver cancer.

In conclusion, the high mortality areas of liver cancer were identified in Central and southwest Guangxi by GIS, and the imbalance in geographic distribution of liver cancer was potentially associated with climate factors such as temperature, precipitation, humidity and barometric pressure. To fully utilize the advantages of GIS technology, in the future the registration of liver cancer incidence and mortality with follow-up, and the number of monitoring sites for environmental and climatic data, must be increased. In addition, a corresponding information-sharing platform must be developed to record and publish basic information about diseases, the climate, and other environmental factors, and even the socioeconomic status of the people of these regions via network carriers and the media. This could provide an online service for researchers in disease prevention and control, policy makers, and the public enabling remote and interactive query with keywords such as disease category, gender, age, region, and time. Only these changes will allow a gradual increase in the accessibility of spatial analysis and its further development for disease control.

Acknowledgements

This research is supported by a grant from Guangxi Natural Science Foundation (2011GXNSFB018082) and National Natural Science Foundation of China (81260319).

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