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Spatial patterns of adolescent drug use

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ABSTRACT

Adolescent drug use is individually and socially harmful in terms of disrupting adolescent development and social cohesion. Prior research has identified populations at risk and risk factors for adolescent drug use. This research sought to contextualize adolescent drug use by examining this behavior from a geographic perspective. The specific objectives were to identify patterns, local clusters and excess spatial risk for 5-digit zip codes within the 5-county Cincinnati, Ohio region. Adolescents ($n = 57{,}241$) were recruited within local schools by the Coalition for a Drug-free Greater Cincinnati. Results of this research show spatial clusters for perceived safety of marijuana; peer approval of alcohol, tobacco and marijuana; and age of onset for other drugs. The location and nature of these clusters are discussed and displayed in-text. Further, zip codes that were in excess risk compared to the 5-county region were identified. The utility of this research is two-fold: (1) It identifies the geographic variability in adolescent drug use and correlated factors of use, and (2) It provides a methodological framework for future research in spatial epidemiology of drug use.

Introduction

Substance abuse is a pressing public health issue today. Substance abuse poses several risks, including risk for dependence, involvement with other risky behaviors, and interference with adolescent development (Squeglia, Jacobus, & Tapert, 2009; Vidourek & King, 2010). Prior research has shown that the likelihood of substance use and abuse increases with age and varies between ethnic groups (Swendsen et al., 2012). Harmful patterns of substance abuse have been studied using a variety of research methods, but until relatively recently the relationship between substance abuse and geography has been comparatively unexplored (McLafferty, 2008).

The traditional epidemiologic triangle of disease (see Fig. 1) describes the relationship between agent (i.e. disease causing agent or behavior), environment, host, and the interplay between these factors (and vectors in some cases) that determines the development and spread of disease (Merrill, 2013). Merikangas and Avenevoli (2000) adapted this model to substance abuse: the agent is the drug; the environment consists of exposure and access related factors such as parental, peer, family and neighborhood influences; and the host as characteristics related to the user(s) such as sex, age, cohort, ethnicity, genetic factors, etc. Prior research has mainly attended to host and agent related topics. Research that has explored environment has generally explained on inter- and intra-personal environments. The examination of the influence of geographic environment, such as community or neighborhood, on substance abuse was considered by McLafferty (2008) to be an emerging area of research, and since then only a limited number of research studies have been conducted using methods to address this issue.

Prior research of the spatial epidemiology of drug abuse has examined the relationship between neighborhood drug availability and drug use among adults (Freisthler, Gruenewald, Johnson, Treno, & Lascala, 2005); the relationship of alcohol consumption and neighborhood availability (Pasch, Hearst, Nelson, Forsyth, & Lytle, 2009; Pridemore & Grubesic, 2012); regional distribution of opioid use (Brownstein, Green, Cassidy, & Butler, 2010); spatial patterns of drug-related behaviors (Brouwer, Weeks, Lozada, & Strathdee, 2008; Stopka et al., 2012); and risk based on social and geographical networks and protective settings (Walker, Mason, & Cheung, 2006).

Adolescent drug use has been shown to be related to problem and risky behavior, poorer academic achievement, interference with cognitive development, and the patterns of use vary among

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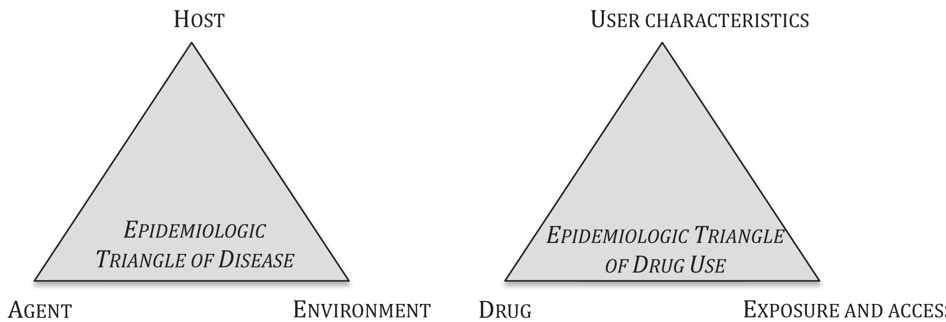

Fig. 1. Epidemiologic triangle of disease and epidemiologic triangle of drug use.

ethnic and age groups (Birckmayer, Holder, Yacoubian, & Friend, 2004; Lonczak et al., 2001; O'Connell, Boat, & Warner, 2009; Squeglia et al., 2009; Swendsen et al., 2012). Prior research has also shown some geographic variability in drug use patterns (Brownstein et al., 2010; Stahler et al., 2007). A contextual analysis can shed light on geographic underpinnings of these known risk factors.

The present study was designed to address geographic variability in adolescent drug use. The findings are instrumental in providing specific focus to drug prevention efforts among adolescents. In other words, examining inequalities between communities and using that information to prevent adolescents from beginning drug use. Specifically, the purpose of this study was to examine spatial patterns of adolescent drug use in the Cincinnati metropolitan region.

The following research questions were examined: (1) What is the spatial pattern of adolescent drug use in the Cincinnati metropolitan region (i.e. random, uniform, clustered)? (2) Are there areas with significantly high or low levels of adolescent drug use while including influence of neighboring areas (e.g. areas with high levels of adolescent drug use surrounded by low level neighbors or areas with high levels of adolescent drug use surrounded by high level neighbors)? and (3) Are there differences in excess risk between neighborhoods for drug use? Drug use was operationally defined as the following: 30-day use, perceived safety, perceived peer/parental approval, and age of onset for tobacco, alcohol, marijuana and other drugs.

By identifying spatial patterns of adolescent drug use in the Cincinnati region the findings from this research directly supports local drug prevention efforts. The results of this study are beneficial for two major reasons. First, the sub-research area of the spatial epidemiology of drug use is emergent. As this area of research is relatively new, findings from this study provide a significant contribution to the research knowledge base by documenting adolescent drug use across a spatial region. Second, the results of this study were anticipated and are to be directly utilized by local coalitions for drug prevention efforts (e.g. preventing drug use from occurring).

Table 1
Demographics.

Grade		Sex		Race	
7th	16.4%	Male	45.8%	White	78.8%
8th	17.1%	Female	48.5%	African American	8.4%
9th	18.5%	No response	5.7%	Latino	2.1%
10th	19.1%			Asian	2.9%
11th	16.2%			Native American	0.7%
12th	12.8%			Multiple	4.2%
				Other	1.5%
				No response	1.6%

Background

Adolescent drug use

The results of the National Comorbidity Survey indicate that roughly two thirds of teenagers have consumed alcohol in their lifetime (Swendsen et al., 2012). There is notable variation between age and ethnic groups, but not between sexes. There is a positive correlation between age and lifetime consumption of adolescents. Hispanic and non-Hispanic white youth had the highest prevalence of use (60.0% and 62.1% respectively), while non-Hispanic black and other had the lowest prevalence of lifetime use (49.3% and 50.2% respectively). These findings parallel the use of illicit drugs among adolescents. Specifically, there is a positive relationship between lifetime use and age; and Hispanic and non-Hispanic white youth were the most likely to have used (Swendsen et al., 2012). Showing that approximately one quarter of adolescents has used marijuana, 2.3% has used cocaine, 5.4% has used prescription drugs, and 3.2% of adolescents have used other drugs (Swendsen et al., 2012).

The literature establishes common risk and protective factors related to adolescent drug and alcohol use. Drug and alcohol use tend to begin in mid-to-late adolescence, and earlier age of onset is related to greater risk of drug and alcohol related problems later in life (Chou & Pickering, 1992; O'Connell et al., 2009). Parental approval and low parental monitoring have also been shown to be a risk factor for drinking and drug use (Donovan, 2004; Shillington et al., 2005). Similarly, drug and alcohol use in the family is a strong predictor of adolescent use (Birckmayer et al., 2004). Other non-parental social problems can pose greater risk for adolescents.

Table 2
Global autocorrelation for drugs and variables.

Variable	Drug	*I*	*p*-Value
30-day Use	Tobacco	−0.056	0.751
	Alcohol	0.019	0.323
	Marijuana	0.043	0.205
	Other drugs	0.004	0.404
Perceived safety	Tobacco	−0.085	0.870
	Alcohol	−0.009	0.486
	Marijuana	0.204	<0.001
	Other drugs	−0.050	0.727
Peer approval	Tobacco	0.054	0.161
	Alcohol	0.100	0.044
	Marijuana	0.134	0.014
	Other drugs	0.145	0.009
Parent approval	Tobacco	−0.061	0.779
	Alcohol	−0.003	0.448
	Marijuana	0.018	0.324
	Other drugs	−0.030	0.614
Avg. age of onset	Tobacco	0.067	0.116
	Alcohol	0.056	0.155
	Marijuana	0.042	0.208
	Other drugs	0.076	0.091

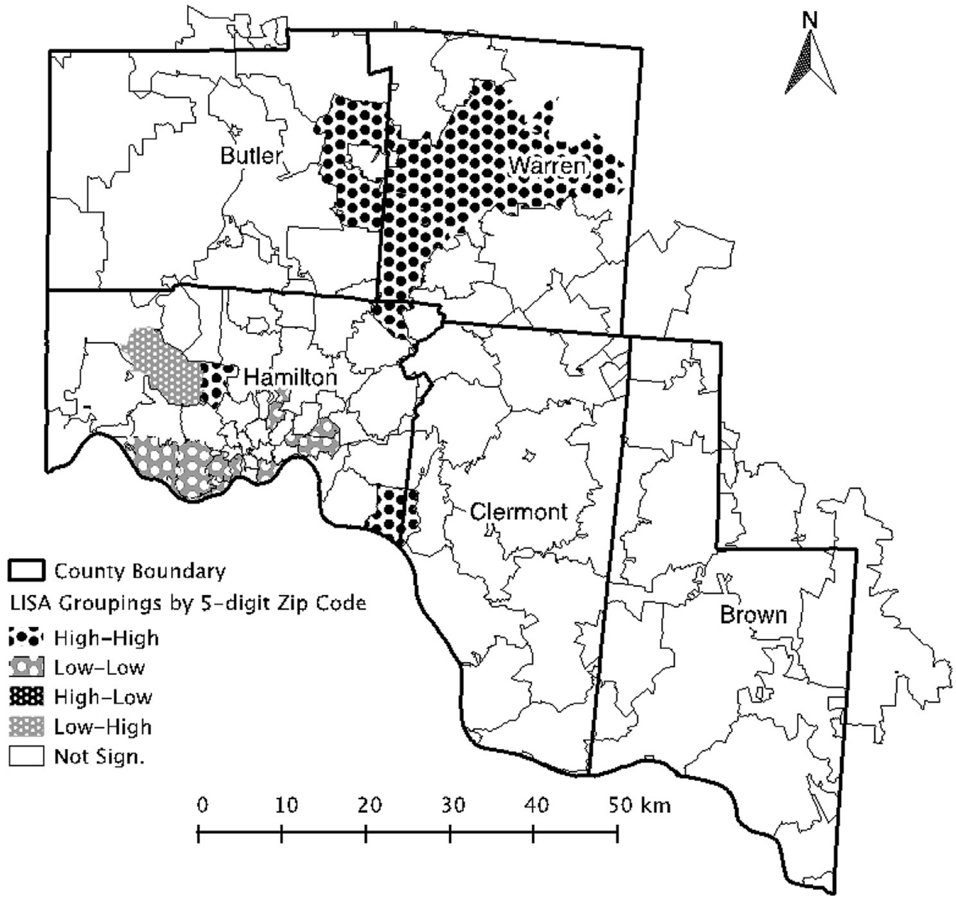

Fig. 2. Clustering of perceived safety of marijuana using local indicators of spatial autocorrelation (LISA).

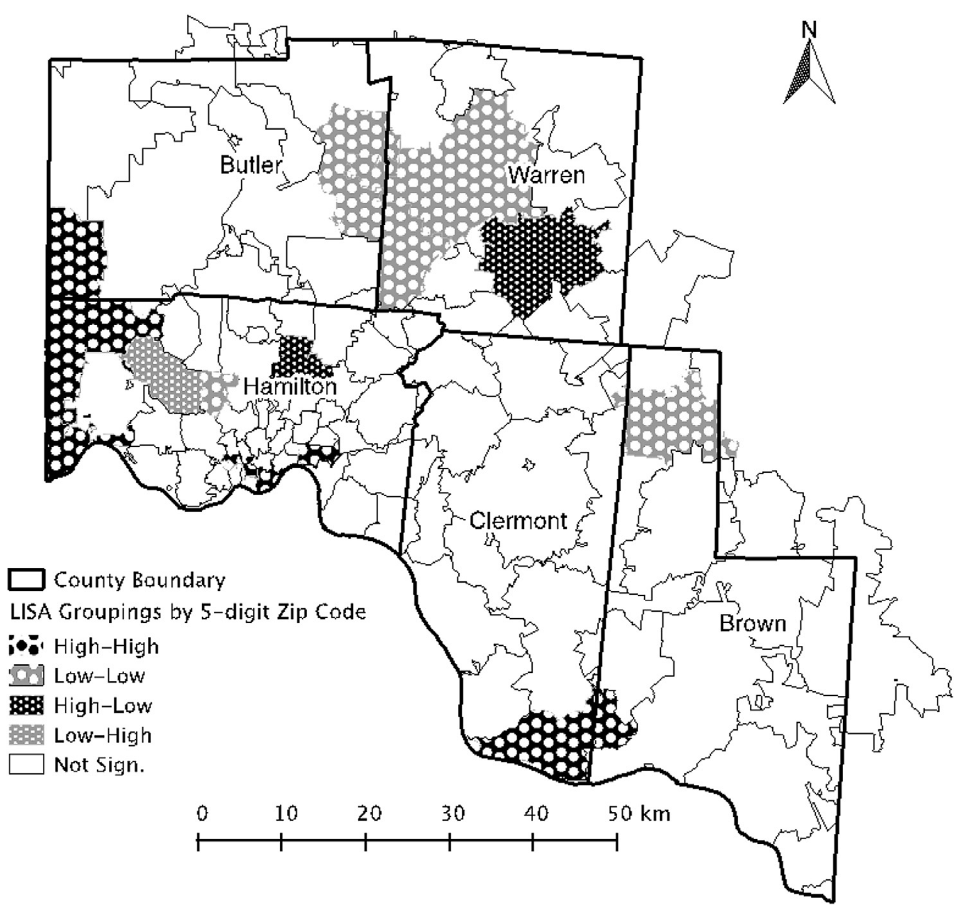

Fig. 3. Clustering of peer approval of alcohol using local indicators of spatial autocorrelation (LISA).

For example, youth who have friendships with youth who use drugs and alcohol, are rejected by their peers, are exposed to peer problem behaviors, and those who are involved in social alcohol and drug use are more likely to experience behavior problems and substance abuse problems later in life (Beck & Treiman, 1996; Dishion & Skaggs, 2000; O'Connell et al., 2009). The majority of drugs and alcohol are consumed via social avenues, and greater availability is related to increased use (Birckmayer et al., 2004; Hawkins, Catalano, & Miller, 1992). Likewise, high perceived safety among adolescents has been found to be indicative of a higher likelihood of alcohol use (Henry, Slater, & Oetting, 2005). Drug use has been shown to be related to academic involvement and performance as well. Additionally, youth who are less involved and who perform more poorly academically are more likely to use alcohol (Lonczak et al., 2001).

Spatial epidemiology of drug use

In health geography the notion of environment refers to any space outside the body (McLafferty, 2008). *Place environment* is often what is being thought of when we think about environmental health. Although *environment* and *place environment* are used interchangeably, place environments are these environments that we live in and have meaning attached to them (Kearns, 1993). The essence of health geography is in exploring the relationship between these geographic place environments and health.

With specific regard to drug use, McLafferty describes three areas where health geography can contribute to drug use research (2008). First, a geographic approach can be particularly beneficial to drug use research by exploring geographic inequalities. Second, this approach contributes by increasing our understanding about the relationships between place environments and health. Thirdly, the geographic approach aids by providing a method useful in analyzing disparities in health care access and location. Examining drug use in its *place* moves beyond individuals and examines the context surrounding this phenomenon. Several methods exist in order to perform this examination and some are described below.

Global spatial autocorrelation. This is a statistical method used to determine what pattern exists globally across a region (i.e. random, uniform or clustered) (Jerrett, Gale, & Kontgis, 2010; Legendre, 1993; Moran, 1948). This technique has been used in public health research with respect to municipal bike accidents, obesity patterns, environmental health research, and in other topics (Chaney & Kim, 2014; Jerrett et al., 2010; Penney, Rainham, Dummer, & Kirk, 2013). Specifically, global spatial autocorrelation analysis determines is inequalities exist across a broad region. For example, Rossen, Kahn, and Warner (2014) found unequal mortality from drug poisoning across the United States of America from 2007 to 2009. Grubesic, Miller, and Murray (2014) likewise used global spatial autocorrelation to determine the existence of spatial inequalities of diabetes prevalence across the United States of America.

Local spatial autocorrelation. While global spatial autocorrelation examines patterns across the region, local spatial autocorrelation accounts for the relationship between place factors for individual units (e.g. zip code, neighborhood) with respect to its neighbors (Anselin, 1995). Although global spatial autocorrelation methods

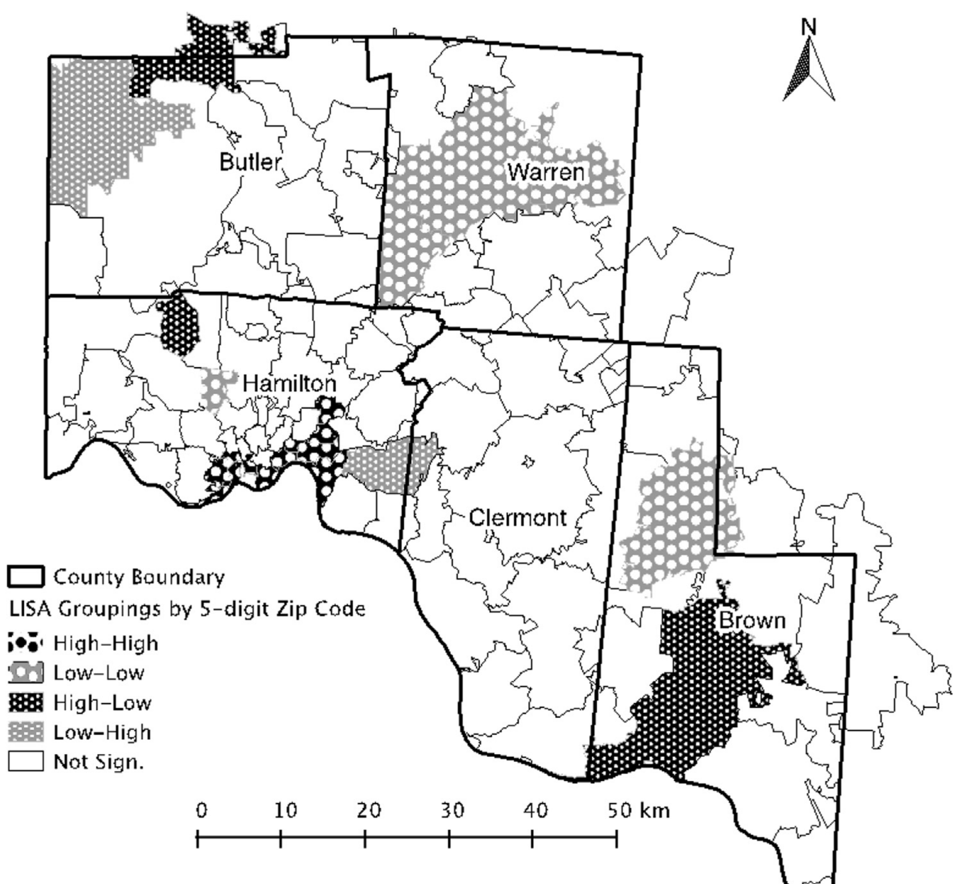

Fig. 4. Clustering of peer approval of marijuana using local indicators of spatial autocorrelation (LISA).

have existed for half a century, it was not until the early 1990s that local methods were developed for identifying clusters (McLafferty, 2008). The local method has been used in a variety of public health research studies ranging from park access and obesity to neighborhood homicides (Messner et al., 1999; Pouliou & Elliott, 2009; Talen & Anselin, 1998). Likewise, Frick and Castro (2013) reported clusters of high tobacco retail density near schools within districts that are social disadvantaged. Sharma (2014) used this same method to identify clusters of high low-density lipoprotein-cholesterol levels (which diabetes increases the risk for) within Mississippi. Sharma discussed these results can be used to more effectively and efficiently target populations within the state for prevention efforts.

Spatial excess risk. Mapping excess risk (also known as spatial relative risk or standard mortality ratio) has been previously documented in the literature (Berke, 2005; Lawson, 2001). Spatial inequalities in health outcomes are due to variations determinants at the individual (e.g. behavior), community (e.g. access to resources), and societal (e.g. health policies) levels leading to clustering. Those nearer clusters would experience increase risk while those outside the cluster would experience less risk. Berke (2005) outlines a method for exploring spatial risk while controlling for background risk. These methods are also discussed by Anselin (2005) and Merrill (2013).

Prior Studies Using Coalition for a Drug-free Greater Cincinnati Adapted PRIDE Student Drug Use Survey (CDFGC-SDUS)

Four primary studies have previously used the Cincinnati-based CDFGC-SDUS data. One study found that Hispanic youth are at higher risk of episodic heavy drinking compared to other ethnic groups. This study explored this issue categorically using odds-ratios and chi-squared analysis to determine these differences (King & Vidourek, 2010). Another study found that, among African-American youth, 30-day use was negatively related to academic performance, participating in school activities, attending church, and having parents/teachers talk about the dangers of alcohol and set/enforce rules regarding alcohol; while recent use was positively related to getting into trouble, skipping school, and having friends who use alcohol and other drugs. This study explored this issue categorically across the aggregated region using odds-ratios and chi-squared analysis (Vidourek & King, 2010). A third study documented the prevalence of 30-day use and frequency of heavy episodic drinking among African-American youth. Also, perceived harm and parent/peer disapproval of substance use was negatively associated with use (Vidourek & King, 2013). A fourth study described the prevalence and categorical differences of marijuana use (King, Vidourek, & Hoffman, 2012). Aside from prevalence, the latter study found that low perceived harm, easy access and low parent/peer disapproval posed greatest risk of using marijuana. This research adds to existing literature by characterizing these inequalities by specific geographic location.

Method

This cross-sectional study used data collected from the 2012 Cincinnati CDFGC-SDUS. A total of 57,241 participants from the 5-county Cincinnati metropolitan region completed the CDFGC-SDUS. A total of 8561 cases were removed for the following reasons: participants provided an invalid zip code (5262 cases

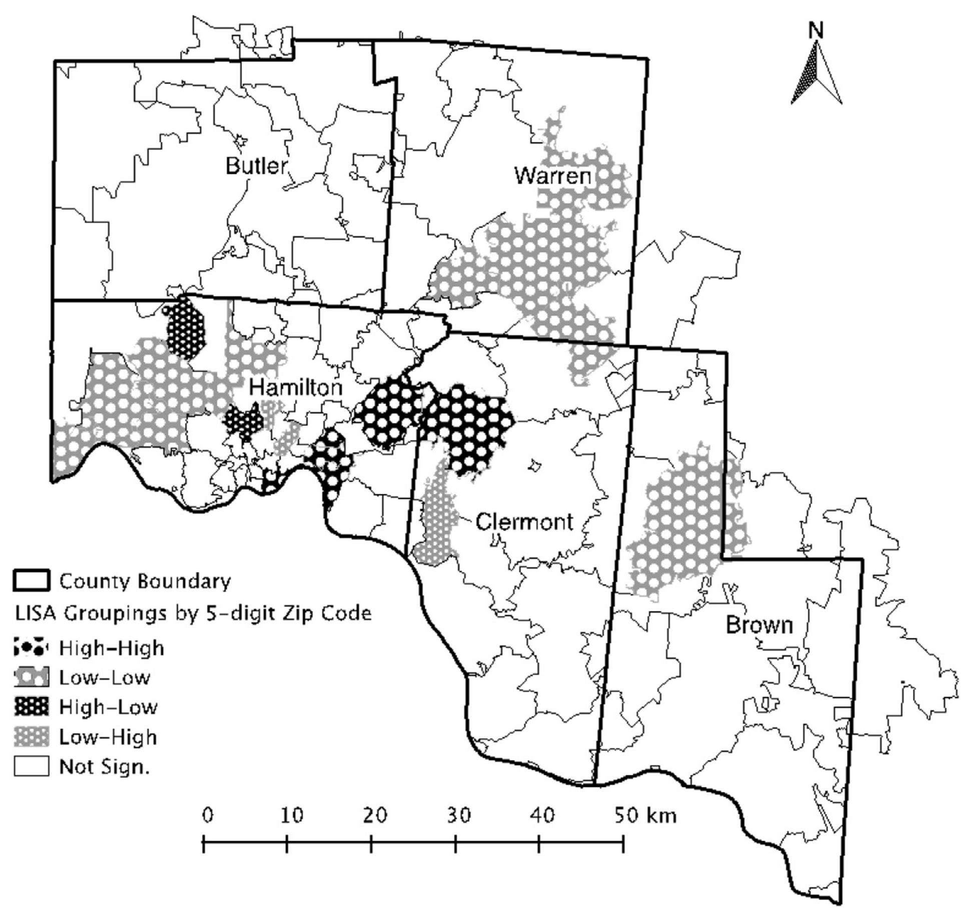

Fig. 5. Clustering of peer approval of other drugs using local indicators of spatial autocorrelation (LISA).

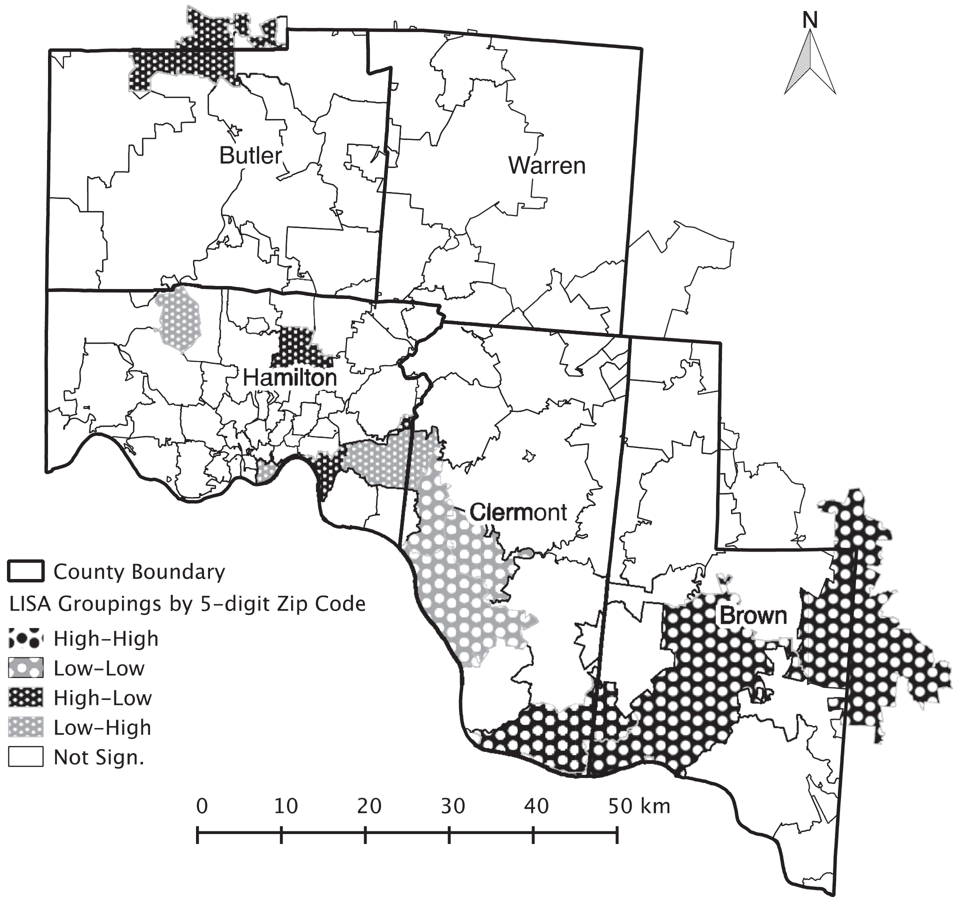

Fig. 6. Clustering of age of onset of other drugs using local indicators of spatial autocorrelation (LISA).

removed), participants lived outside the 5-county region (3167 cases removed), or participants resided in very small zip codes which would cause problems with contiguity of spatial weights (132 cases removed). Ultimately, there were 48,680 usable cases for analysis. Zip code was the geographic variable used in this study. Prior public health research has justified using zip code as the geographic variable (Gruenewald et al., 2013; Johnson, Gruenewald, & Remer, 2009; Smith, Irish, Wang, Haddox, & Dart, 2008). Likewise, Freisthler et al. (2005) measured alcohol outlet density and police incidents by zip code and their relation to child abuse. Anderson et al. (2009) explored zip code level factors related to GHB intoxication. Gruenewald and Remer (2006) explored how violent injuries are related to population and physical characteristics at the zip code level. Brownstein et al. (2010) described clustering of prescription drug abuse at the state level using 3-digit zip codes. Relating findings to specific communities or municipalities can, in some cases, be problematic due to misalignment (e.g. differing data set boundaries as with zip codes and school districts) and should be interpreted with that consideration.

The Coalition for a Drug-free Greater Cincinnati (CDFGC) is a regional coalition whose mission is to prevent and reduce drug use among adolescents across the Cincinnati metropolitan region. CDFGC recruited school participation via mail, phone, email, and through local coalition partnerships. Student participation was voluntary. Survey administrators informed students about the

Table 3
Local map clusters and areas of spatial relative risk identified.

Map	(+)	(−)
Perceived safety: marijuana	Warren Co., SE Hamilton Co.	South Hamilton Co., Cincinnati city-center
Peer approval: alcohol	W Hamilton Co., Cincinnati city-center, S Clermont Co.	Warren Co.
Peer approval: marijuana	Cincinnati city-center, Brown Co., N Butler Co.	Warren Co.
Peer approval: other drugs	Cincinnati city-center, NE Hamilton Co.	W Hamilton Co., Warren Co.
Age of onset: other drugs	Cincinnati city-center, N Butler Co., Brown Co.	SE Hamilton Co., N Hamilton Co., Cincinnati city-center
	Top 3 high risk	*Bottom 3 low risk*
Rel. risk: marijuana	N Butler Co., NE Hamilton Co., S Butler Co.	N Brown Co., NW Butler Co, Cent. Butler Co.
Rel. risk: alcohol	N Butler Co., SE Warren Co., S Clermont Co., NE Hamilton Co.	NW Butler Co., N. Brown Co., Cent. Hamilton Co.
Rel. risk: tobacco	N Butler Co., S Butler Co., NE Hamilton Co.	NW Butler Co., Cent. Hamilton Co., S Warren Co.
Rel. risk: other drugs	NW Warren Co., NE Hamilton Co., Cincinnati city-center	NW Butler Co., W Hamilton Co., Cent. Hamilton Co., SE Warren Co.
Rel. risk: all drug types	Central Butler Co., Cincinnati city-center, N Clermont Co.	Central Hamilton Co., NE Hamilton Co., N Brown Co.

purpose of the survey, the confidential nature of the survey, and the importance of providing honest answers. Each student in a participating school was given a survey to complete on the date of survey administration.

Instrumentation and materials

Individual data were collected via the Coalition for a Drug-free Greater Cincinnati adapted PRIDE Student Drug Use Survey (CDFGC-SDUS). Originally developed in the late 1980s, CDFGC began using the survey system in 2000. The whole of the instrument has remained unaltered since 2000, but a few questions have been added with respect to prescription drug use and suicide behavior. Edits were suggested and validated by the research committee within CDFGC, which includes academic researchers, physicians, drug prevention experts, community health coalition members and survey researchers. The instrument has been shown by previous research to be valid and reliable (Adams, 1994; Craig & Emshoff, 1987; Metze, 2000). The survey was made up of 13 sections covering the following topics: personal and family information, student information, prior drug use, effect of drug use, perceived harm, age of onset, location of use, time of use, non-medical use, ease of access, perceived disapproval of friends/family of using, safety behavior at school, and safe school locations. The variables used in this study were 30-day use, peer/parental approval, perceived safety, age of onset, and geography for tobacco, alcohol, marijuana and other illegal drugs. Questions used to collect these variables are presented in Supplementary Table 1.

As previously reported by Metze (2000), reliability testing was performed with $n = 631$ students from three locales. The survey was administered twice and a correlation coefficient was calculated between times. Correlation values were high (most greater than 0.90) for personal and family information section. Correlation values ranged from 0.513 to 0.867 for the student information section; most questions less than 0.70 had an exact agreement of greater than 0.80 indicating a weak but acceptable correlation over time. Questions with major disagreement in this section dealt with communication between student/teacher, peer, and parent. Correlation values were above 0.618 for tobacco, alcohol and marijuana and 0.500 for other drugs in the perceived harm of drug use; all exact agreement values were greater than 60%. It is hypothesized the weaker reliability for this section is due to the question asking students about a qualitative measurement (i.e. “How do you feel…”) compared to a quantitative measurement (i.e. “How many times…”) (Metze, 2000). Questions in the drug use frequency section demonstrated high test–retest correlation with the exception of inhalants, which had a high exact match. Questions about age of onset generally had high correlation values and all exact agreement values between test-times were greater than 80%.

Data analysis

Software for data analysis

Data analysis was performed using two software programs. Data management and spatial analysis was conducted using R statistical software (version 3.0.1) (R Core Team, 2013). Visualization of spatial

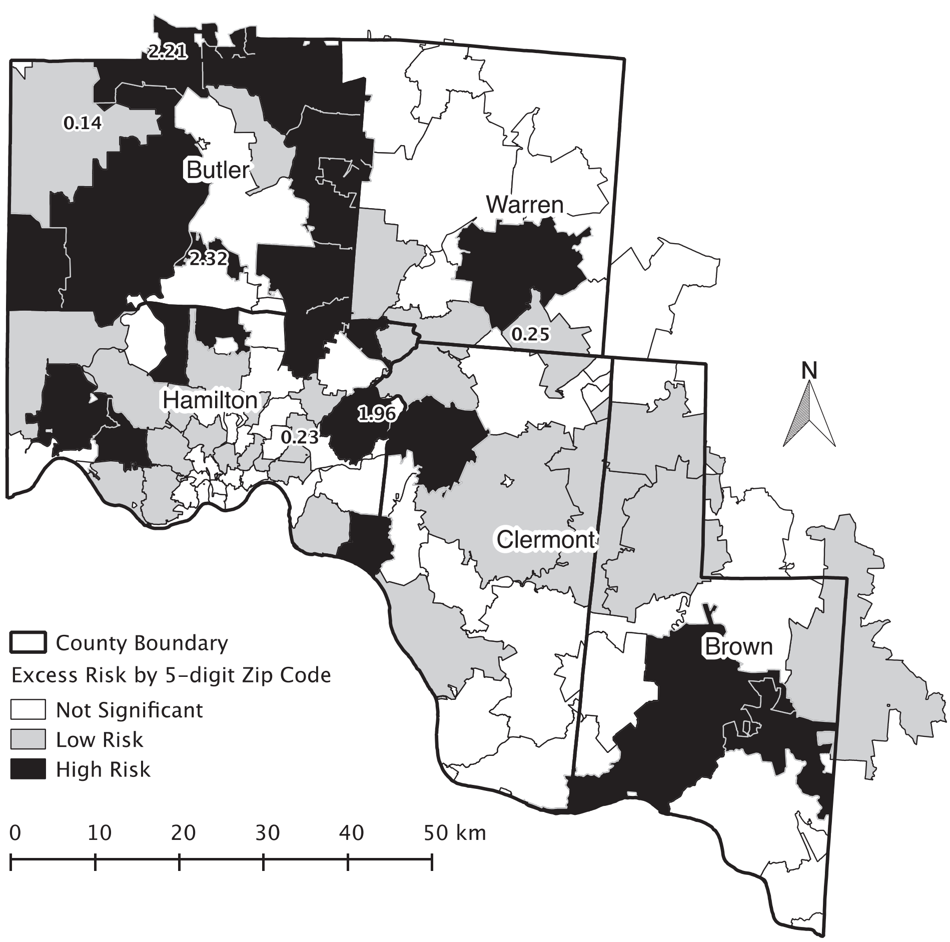

Fig. 7. Spatial excess risk map of tobacco use.

data and management of shapefiles was performed using QGIS (version 2.0) geographic information system software (QGIS Development Team, 2013).

Assessment of research questions

Assessing if there is a regional global spatial autocorrelation (i.e. pattern) of drug use was determined using the Global Moran's I statistic (Anselin, 2005; Anselin, Syabri, & Kho, 2006; Moran, 1948). There are some similarities to non-spatial bivariate correlation. First, Moran's I is bounded by -1 and $+1$. Second, it compares how similar points (or areas in the case of zip codes) are to one another across a broad region (thus, the "global" Moran's I). The interpretation of this statistic is as follows: values nearer to -1 indicate a uniform distribution (i.e. dispersion); values nearer to 0 indicate a random distribution; and values nearer to $+1$ indicate a clustered pattern.

Determining the local spatial autocorrelation was determined using the local indicators of spatial autocorrelation (LISA) method outlined by Anselin (1995). This measure shows the extent to which points that are close to a given point or region (e.g. zip code) have similar values. Each geographic unit receives a measure of spatial autocorrelation and is compared to its neighbors. Results are usually broken down into four categories: "high–high" meaning the individual unit possesses a high observation and its neighbors are also high (In practice this is a high standardized observation of a high standardized spatial lag (average of weighted neighbors) and a low p-value for the local Moran's I test (being adjusted for by k number of neighbors)); "high-low" meaning the individual unit is high but its neighbors are low; "low-high" meaning the individual unit is low but its neighbors are high; "low–low" meaning the individual unit is low and its neighbors are also low; and "Non-significant." These can be displayed geographically to identify hot and cold spots (Anselin, 2005).

Spatial excess risk was calculated by comparing observed values with expected values for each zip code in the region. As previously described, spatial excess risk for an area (also known as spatial relative risk or standard mortality ratio) is the ratio of the observed count and the expected count for that area. The expected count is the product of the overall regional rate and the population at risk within the zip code (Anselin, 2005; Merrill, 2013). The population at risk for each zip code was defined as any adolescent age 12–18 years old and counts were retrieved from U.S. Census for the same year the adolescent drug use data was collected (U.S. Census Bureau, 2011). Statistical significance was determined using 95% confidence intervals: intervals not containing one and where both limits were less than one were considered statistically significant "low risk"; intervals not containing one and where both limits were greater than one were considered statistically significant "high risk".

Results

Participants were equally represented across grades and by sex. The majority of participants were White (78.8%) followed by African American (8.4%). This demographic breakdown is comparable to the regional rates for these race groups (U.S. Census Bureau,

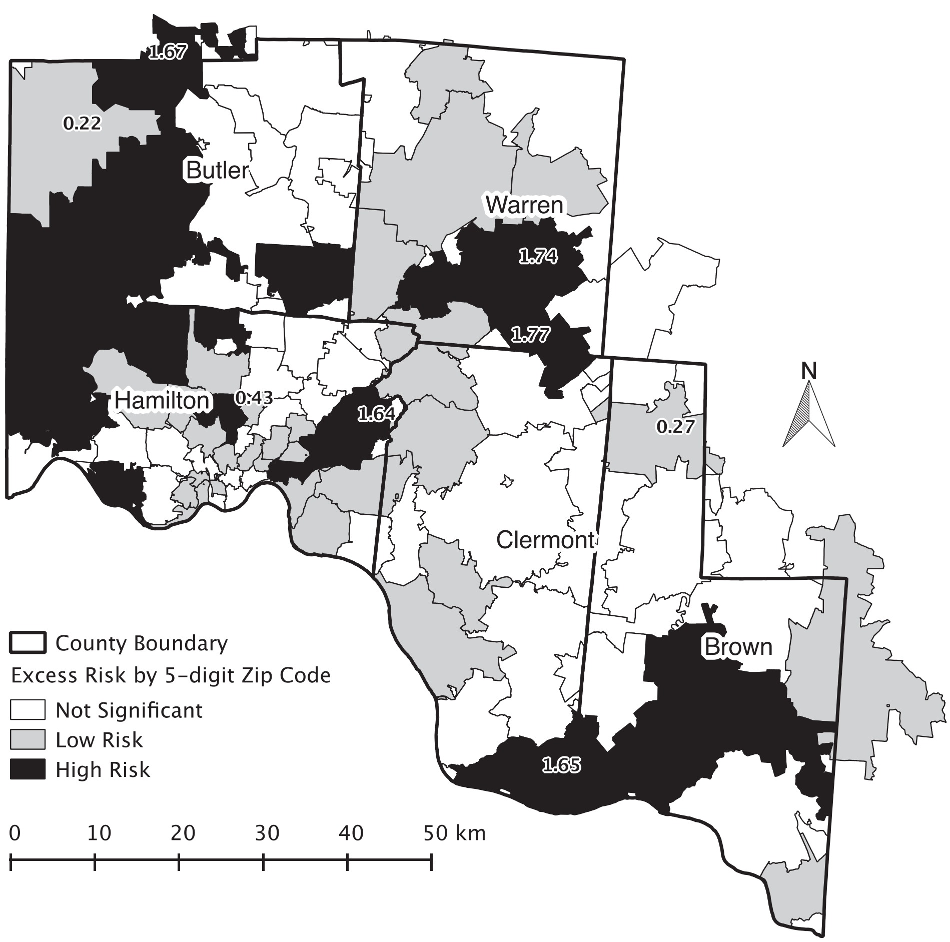

Fig. 8. Spatial excess risk map of alcohol use.

2011). Table 1 presents the full demographic breakdown of participants.

Results for global spatial autocorrelation are presented in Table 2. There was a significant clustering pattern observed for several variables: perceived safety of marijuana ($I = 0.204$, $p < 0.001$); peer approval for alcohol ($I = 0.100$, $p = 0.044$), marijuana ($I = 0.134$, $p = 0.014$), and other drugs ($I = 0.145$, $p = 0.009$); and age of onset for other drugs ($I = 0.076$, $p = 0.091$).

Variables that presented significant global spatial autocorrelation were examined at the local level using Local Indicators of Spatial Autocorrelation (LISA). Fig. 2 shows local clustering of adolescent perceived safety of marijuana. Figs. 3–5 shows local clustering of peer approval of alcohol, marijuana, and other drugs. Fig. 6 shows local clustering of age of onset for other drugs. A tabular form of Figs. 2–6 is presented in Table 3 where communities are identified with respect to cluster types. Community types include rural, suburban and urban areas of the Cincinnati metropolitan region. Results for spatial excess risk showed variation across the 5-county region. Top high-risk and low-risk communities are identified in Table 3. Figs. 7–11 depict these rates.

Discussion

This study examined spatial patterns of adolescent drug use across the Cincinnati metropolitan region. It sought to describe if a spatial pattern of drug use exists, and if it does what is the nature of that pattern. This study examined the excess risk of adolescent drug use by 5-digit zip code relative to the 5-county region.

A statistically significant clustering pattern was identified for perceived safety of marijuana; peer approval for alcohol, marijuana, and other drugs; and age of onset for other drugs. Each of these was in turn examined at the local level using the LISA method. Age of onset for other drugs showed a weak clustering pattern. It was not significant at the usual $\alpha = 0.05$ level, but was significant at the $\alpha = 0.10$ level and practical significance warranted further investigation. A key finding showed there were clusters of peer approval for alcohol, marijuana and other drugs. This means there is variation across the region; some areas with high peer approval and some areas of low peer approval. This was not the case for tobacco though, where the perception of peer approval was random. Another key finding is that the age at which adolescents begin using other drugs varies geographically. These findings support prior research by providing further evidence that drug use and drug-related behavior varies across geography. For example, Brownstein et al. (2010) describe clusters of opioid abuse at the state level. Their findings are suggestive of communities in greatest need of intervention and public health assistance. Petronis and Anthony (2003) likewise found clusters of first-time cocaine users within U.S. cities, which were related to socio-demographic factors. Recognizing that spatial variation exists and identifying geographic areas of greatest need stands as a critical component of health promotion and education work. These clusters were analyzed using spatial lag regression models in attempt to characterize them. The variables with significant clustering acted as the dependent variable and predictor variables included income levels, parental educational attainment (Soteriades & DiFranza, 2003), diversity

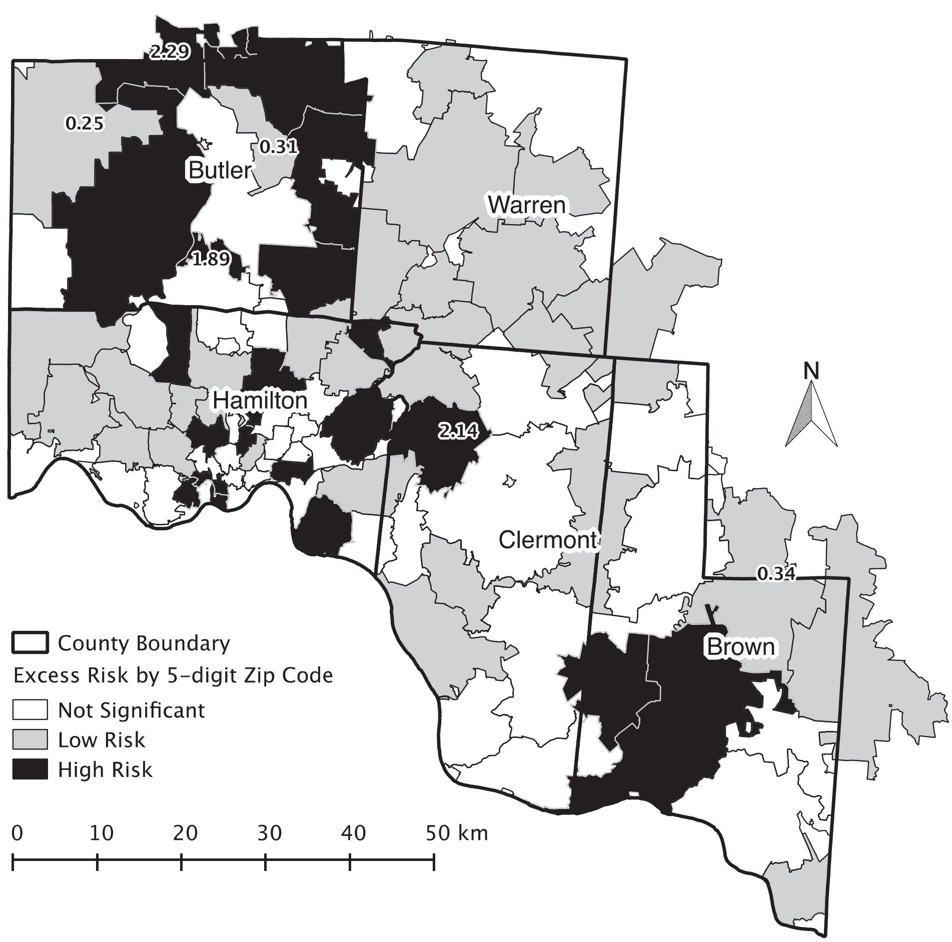

Fig. 9. Spatial excess risk map of marijuana use.

index (Maly, 2000), family living structure for students (e.g. live with both parents) (Hoffmann & Johnson, 1998), student employment (Bachman & Schulenberg, 1993; Wu, Schilenger, & Galvin, 2003), perceived access to drugs, monthly drug use, community engagement (e.g. clubs, sports, church, etc.), parent involvement (e.g. communication, expectations, consequences for use), school involvement, and buying/selling drugs at school. The results of these models show two primary findings: (1) That across multiple models monthly drug use and perceived drug access were significant predictors for their respective drug; and (2) few of the models demonstrated a clear spatial dependence, and indicated my the non-significant rho values. Many of the models had non-significant predictors also. This demonstrates the gap in understanding regarding spatial patterns and the need for future research in this area. The results from these findings are presented as a Supplementary table.

Analysis used to characterize the clusters identified at the global level yielded evidence of geographic variation among these variables. These local clusters demonstrate that drug use behavior and related perceptions occurs in urban, suburban, and rural settings. This is evidenced when looking at the top at-risk communities for other drugs that include communities from NW Warren County (rural), NE Hamilton County (suburban), and Cincinnati city-center (urban) (see Table 3). It is interesting to note that adolescents in Warren County perceived using marijuana as safe, but they felt their peer would not approve of their use, nor that of alcohol or other drugs (see Table 3). Oppositely, adolescents in two different Cincinnati city-center communities felt that marijuana use was not safe and that their peers would approve of their use, along with alcohol and other drugs. Peer and parental approval of drug use has previously demonstrated as predictors of adolescent use (Beck & Treiman, 1996; Dishion & Skaggs, 2000; O'Connell et al., 2009). Warren County had several areas of significantly low risk for marijuana use, but the Cincinnati city-center communities both were high risk areas for marijuana use (see Fig. 9). A rural community in North Butler County also was a hot spot for high peer approval for marijuana and was a top at risk community for marijuana, alcohol, and tobacco use. This finding is also reflected in the assessment of risk for all drug types (see Fig. 11). This finding is supported by prior research showing the influence of peers on drug use, but adds to the literature by demonstrating a methodology to contextualize these findings (Dishion & Skaggs, 2000). A suburban community in NE Hamilton County had an unusually high level of peer approval for other drugs and was a high risk community for adolescent use of other drugs. NW Butler County was a low risk community for alcohol, marijuana, tobacco and other drug use among adolescents. This research suggests a relationship between community level risk and determinants of adolescent drug use. The SE Hamilton County area also had large cluster of low age of onset of other drugs while having pockets of high risk for adolescent other drug use. The relationship between earlier age of onset and greater risk for related problems has been documented in prior research (Chou & Pickering, 1992; O'Connell et al., 2009). Identifying communities with lower on-average age of onset can aid in efforts to prevent the outcomes of drug abuse.

This study has acknowledged inherent limitations. Data were collected using self-report surveying seventh through twelfth grade students at participating schools in 2012. Only cases that

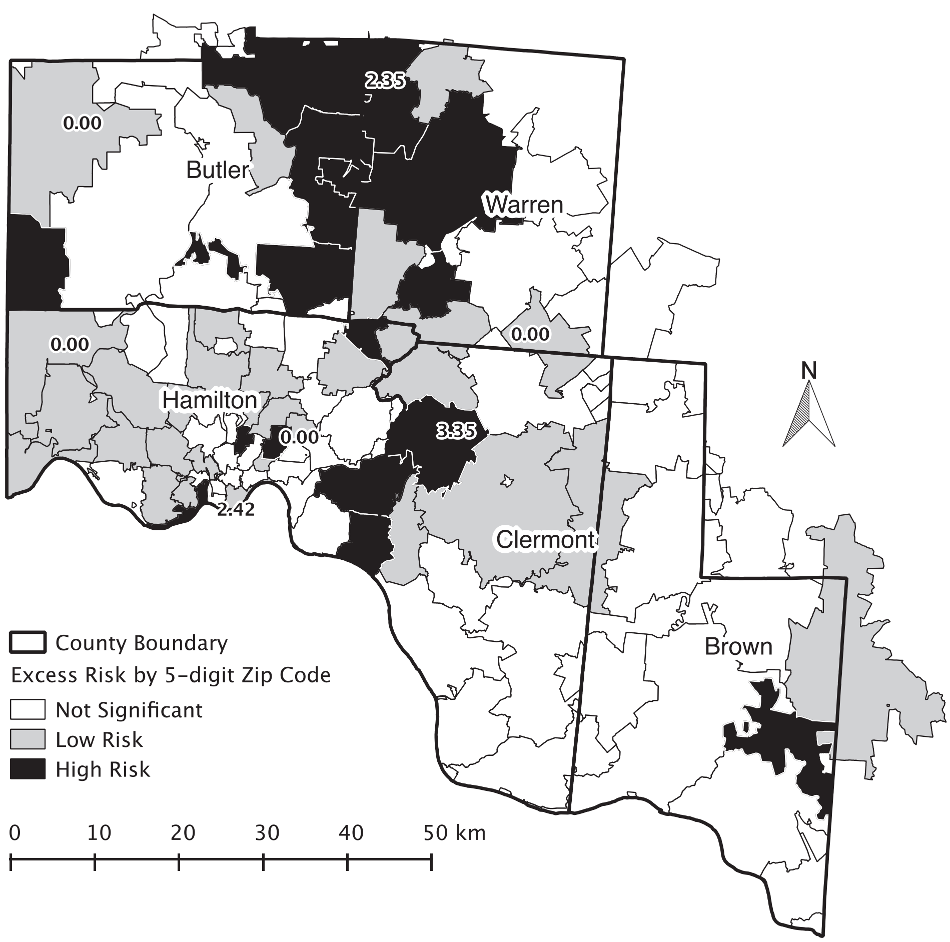

Fig. 10. Spatial excess risk map of other drug use.

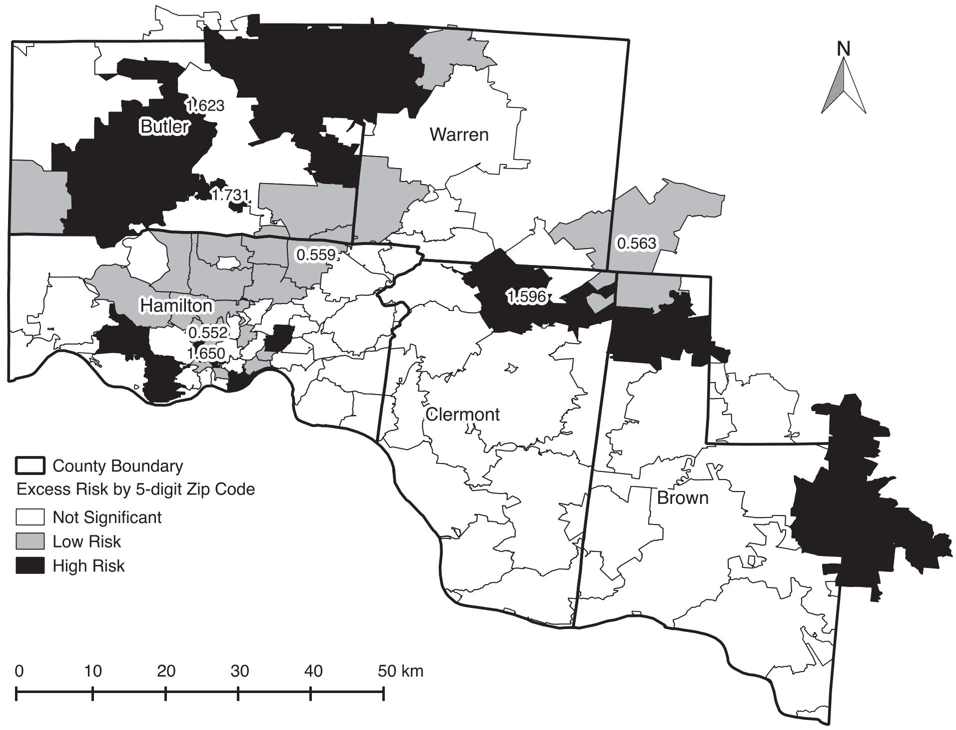

Fig. 11. Spatial excess risk map of all drug use.

contained a valid zip code in the geographic region were used. The results of this study are generalizable to adolescents in the Cincinnati region. The specific results are not generalizable to other communities because of the unique geographic nature of this research. However, the methods and findings that spatial patterns do exist across a large metropolitan region are applicable other areas of research.

Future research should focus on describing differences between communities with high and low rates of use in this region. An attempt was made to characterize the differences between clusters in terms of spatial lag regression, which demonstrate the need for future research in this area. Examining the interaction of individuals within communities, and not simply and areal analysis, would yield greater understanding how communities differ from one another thereby contributing to prevention and intervention efforts. This can be done by examining in-depth individual use behaviors and their contributing factors within each community, including where adolescent are using drugs. Another future step is to use this information to inform local community health efforts.

This research has demonstrated that spatial clusters of drug use behavior and perceptions exist across a large metropolitan region. These clusters vary based on their geographic location and direction (i.e. high or low). Risk of adolescent use also differs by community compared to the larger geographic area. This methodology can be applied to other drug use scenarios to identify at-risk communities and allocate resources for prevention and intervention efforts.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.apgeog.2014.11.002.

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