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Investigating Crime Hotspot Places and their Implication to Urban Environmental Design: A Geographic Visualization and Data Mining Approach

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***Abstract*—**Information is power. Geographical information is an emerging science that is advancing the development of knowledge to further help in the understanding of the relationship of "place" with other disciplines such as crime. The researchers used crime data for the years 2004 to 2007 from the Baguio City Police Office to determine the incidence and actual locations of crime hotspots. Combined qualitative and quantitative research methodology was employed through extensive fieldwork and observation, geographic visualization with Geographic Information Systems (GIS) and Global Positioning Systems (GPS), and data mining. The paper discusses emerging geographic visualization and data mining tools and methodologies that can be used to generate baseline data for environmental initiatives such as urban renewal and rejuvenation. The study was able to demonstrate that crime hotspots can be computed and were seen to be occurring to some select places in the Central Business District (CBD) of Baguio City. It was observed that some characteristics of the hotspot places' physical design and milieu may play an important role in creating opportunities for crime. A list of these environmental attributes was generated. This derived information may be used to guide the design or redesign of the urban environment of the City to be able to reduce crime and at the same time improve it physically.

***Keywords*—**Crime mapping, data mining, environmental design, geographic visualization, GIS.

I. Introduction

ADVANCES in information technology have opened new opportunities for the use of automated crime mapping. The cutting-edge capability of GIS for geographic visualization and data manipulation can provide the platform for studying the ecological aspects of crime. Fig. 1 graphically presents the ecology of crime and the physical environment - the urban physical environment provides the opportunity for crime as it is where the victim and the offender converge in space and time. To explore and discover relationships of crime and urban geography entails creativity on the part of the user. Data mining or knowledge discovery within the GIS environment may provide useful relationships and unique patterns.

Crime has an inherent geographical quality [1]. When crime occurs, it happens at a place with a geographical location. The study of crime has traditionally been the preserve of other disciplines such as sociology and psychology and it was only in the late 1970s that the "place" and geographic dimension of crime became more fully explored. Studies have been conducted explaining the link between criminal behavior and the physical or social environment.

Fig. 1 Ecology of crime and environment

Environmental sociologists and criminologists have posited that there is a link between criminal behaviors to physical or social space. They argue that crime must be viewed in the context of the place where it occurs because such places present bigger or lesser opportunities for criminal behavior [2],[3], [4], [5], [6]. Further, empirical studies have shown that crime is concentrated in a few "hotspots" [7] which were further defined as very small micro units of analysis, such as buildings or addresses, block faces or street segments; or clusters of addresses, block faces or street segments [8].

This research aims to employ a methodology that shall use exploratory graphics coupled with knowledge discovery tools – geographic visualization and data mining. It shall delve into an emerging research field that was defined as the fusion of

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automated visualization and statistical techniques for detecting patterns within large volumes of spatial data [9].

II. Overview of the Literature And Problem Statement

A. Environmental Criminology

The spatial models of crime were based from a mainstream criminology theory called environmental criminology which is defined as the study of criminal activity and victimization and how factors of space influence offenders and victims [10], [11], [12]. Environmental criminology is not to explain why a specific offender commits a specific crime but to understand the various aspects of a criminal event in order to identify patterns of behavior and environmental factors that create opportunities for crime [13]. Environmental criminology evolved from spatial studies of crime which started almost 200 years ago [14] starting from the cartographic school in the early 1800's to the current stage called the GIS school.

The GIS School was sparked by the growing interest on the complementary fields of geography and environmental criminology. According to Chainey and Ratcliff [15], the catalyst for this phenomenon is the growth of a discipline that addresses space management, architectural design, and urban planning in an attempt to reduce crime. Among the theories advanced by the new environmental criminologists were: (a) the "opportunity theory" put forward by C. Ray Jeffery [16] and Oscar Newman [17] which initially established the relationship between urban design and crime rates by suggesting that physical design can be used to prevent crime by reducing the opportunities; (b) the "expanded opportunity theory" by Clarke and Mayhew [18], Paul and Patricia Brantingham [19], Greenberg and Rohe [20], and Shaw and McKay [21] where they have shown that certain physical attributes such as specific land uses, street layouts, environmental disrepair and deterioration, and physical features that block visibility and natural surveillance can encourage higher incidence of crime; (c) the "broken windows theory" by Wilson and Kelling [22] who stated that physical incivilities (trash, graffiti, abandoned buildings, disrepair, unkempt lots) and social incivilities (rowdy behavior, drug dealing, public drunkenness, prostitution, panhandling and loitering) result in higher crime and fear of crime; and (d) the "rational choice" theory by Brantingham and Brantingham [23] where they argued that criminal events are most likely to occur in areas where the activity space of offenders overlaps with the activity space of potential victims/targets.

The theories developed by the environmental criminologists explained that crime could be understood in more depth by exploring its geographical components. This relationship can be investigated in the form of crime mapping with GIS because this tool can provide the medium within which crime data can be layered with geographic base maps and environmental data that represent the place and milieu of the area where a particular crime is associated. GIS can go beyond its early definition as simply a method of computing because when it is used as a platform for geographic visualization and data mining, it has the potential of identifying valid, novel, potentially useful and ultimately understandable patterns in data [24].

B. Spatial Statistics and Decision Tree Algorithms

Crime does not occur randomly [25]. There are two spatial processes that are fundamental to an appreciation of crime patterns: spatial dependence and heterogeneity. Spatial dependence can be described as the degree to which the value of a variable at one location is influenced by neighboring locations. The basis for the idea stems from Tobler's First Law of Geography which states that "everything is related to everything else, but near things are more related than distant things" [26]. Spatial dependency suggests a clustering of like values as well as the possibility of dispersion of values, so that high value areas are surrounded by low value areas. The converse of spatial dependency is spatial heterogeneity. Crime patterns display spatial heterogeneity simply in their variation from one place to another. Spatial heterogeneity is one of the main reasons why spatial crime patterns are studied - to discover why some places are victimized more than others.

Centrographic statistics is a descriptive statistic which demonstrates the spatial location and distribution of point patterns [27]. A mean center calculation based on Euclidean distance for projected data can be used as an overall description of the central focal point of the data. The mean center is calculated as:

$$\bar{X} = \frac{\sum x}{N} \quad , \quad \bar{Y} = \frac{\sum y}{N} \tag{1}$$

The standard distance is used in conjunction with the mean center both to indicate the focal center of the data series and to provide an indication (albeit a non-directional one) of the distribution of the data around the mean center [28]. The calculation is:

$$SD = \frac{\sum d2}{N} \tag{2}$$

, where N is the number of points in the dataset and d is the distance of each point to the mean center, computed as:

$$d = \sqrt{(\bar{X} - X)^2 + (\bar{Y} - Y)^2} \tag{3}$$

Standard deviational ellipses can be thought of as a directional equivalent of the standard distance [29]. It is a way of measuring the trend of a set of points by calculating the standard distance separately in the x and y directions. The ellipse not only gives an indication of the dispersal of the points but the direction of the longer axis of the ellipse indicates the predominant alignment of data dispersal [30].

The mean center, standard distance and standard deviation ellipse are considered as global statistical tests that could initially help understand general patterns of crime data [31]. The next step is to subject the crime data to deeper analysis especially when crime densities (or hotspots) are required.

Cluster analysis is one of the more popular approaches for the detection of crime hotspots [32]. Since crime is not spread evenly across geographic space, it clumps in some areas and is absent in others. Hotspots are areas of concentrated crime.

To be able to visualize the density and distribution of crime as well as to identify hotpots, the most suitable method is to present it as a continuous surface using kernel density estimation [33], [34]. This method creates a smooth surface of the variation in the density of point events across an area. The method is described in the following steps:

1. A fine grid is generated over the point distribution;
2. A moving three-dimensional function of a specified radius visits each cell and calculates weights for each point within the kernel's radius. Points closer to the center receive a higher weight and therefore contribute more to the cell's total density value; and
3. Final grid cell values are calculated by summing the values of all circle surfaces for each location.

The formula for kernel density estimation is:

$$\frac{3}{k}(1-t^2)^2, t \leq 1 \qquad (4)$$
$$= 0, t > 1$$

The kernel density estimation method requires two parameters to be set prior to running. These are the grid cell size and bandwidth (search radius). Bandwidth is the parameter that will lead to most differences in output when varied [35]. Guidelines exist for working out suitable values for these two parameters. For crime mapping applications, a suitable method to follow for choosing bandwidth is that suggested by Williamson *et al.* [36], where the bandwidth relates to the mean nearest neighbor distance for different orders of k. Users are also required to specify a grid cell size. This can be regarded as a positive feature in kernel estimation because users have the flexibility to set sizes relevant to the scale at which the output will be viewed.

The visualization provided by centrographic statistics and kernel density estimation when combined with other statistical tools may provide valuable insight for detecting areas of concern [37]. Statistical approaches for cluster analysis may be used to confirm the information gathered from geographic visualization.

Decision trees are one of the fundamental techniques used in data mining [38]. They are tree-like structures used for classification, decision theory, clustering, and prediction functions. Decision tree algorithms or CHAID (Chi-squared Automatic Interaction Detector) analysis studies the relationship between a dependent variable and a group of predictor (or independent) variables to find those that best predict the dependent measure. CHAID is an exploratory method for classifying categorical data and the purpose of the procedure is to split a set of objects in a way that the subgroups (or segments) differ significantly with respect to a designated criterion [39]. The segments derived by CHAID are therefore mutually exclusive and exhaustive in the sense that the segments do not overlap and each object of the sample is contained in exactly one segment.

CHAID analyses the instances of explanatory variables and the criterion variables for significant differences. A contingency table is generated with Y as the dependent and X as the predictor and the possible interactions between both variables are identified by their combined frequencies. If no interaction between the variables exists, it can be expected that the relative frequencies of the criterion variable Y within each category of the predictor X correspond to the marginal frequencies of Y [40].

C. The Research Problem

This study endeavors to test the theory of the ecology of crime and design in the urban setting of Baguio City. It aims to venture into a new research path by doing away with subjective crime perception surveys and instead move into the fields of geographic visualization and data mining. It shall try to exploit crime data in order to accurately identify the locations of hotspot places and objectively evaluate their physical environmental attributes which may encourage crime. It shall further undertake to investigate which environmental variables affect which types of crime. Through this innovative approach, it is hoped that new 'nuggets' of knowledge can be discovered.

III. Materials and Methods

Fig. 2 shows the location of Baguio City which is a major urban centre in the northern region of the Philippines. It has a total land area of 54.65 square kilometers. It was originally conceived by the Americans to be a rest and recuperation town in the early 1900's because of its cool climate and unique highland environment.

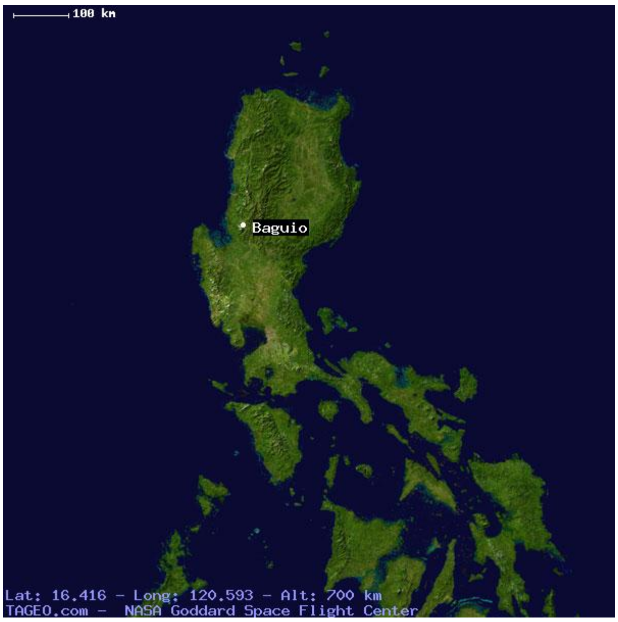

Fig. 2 Location map

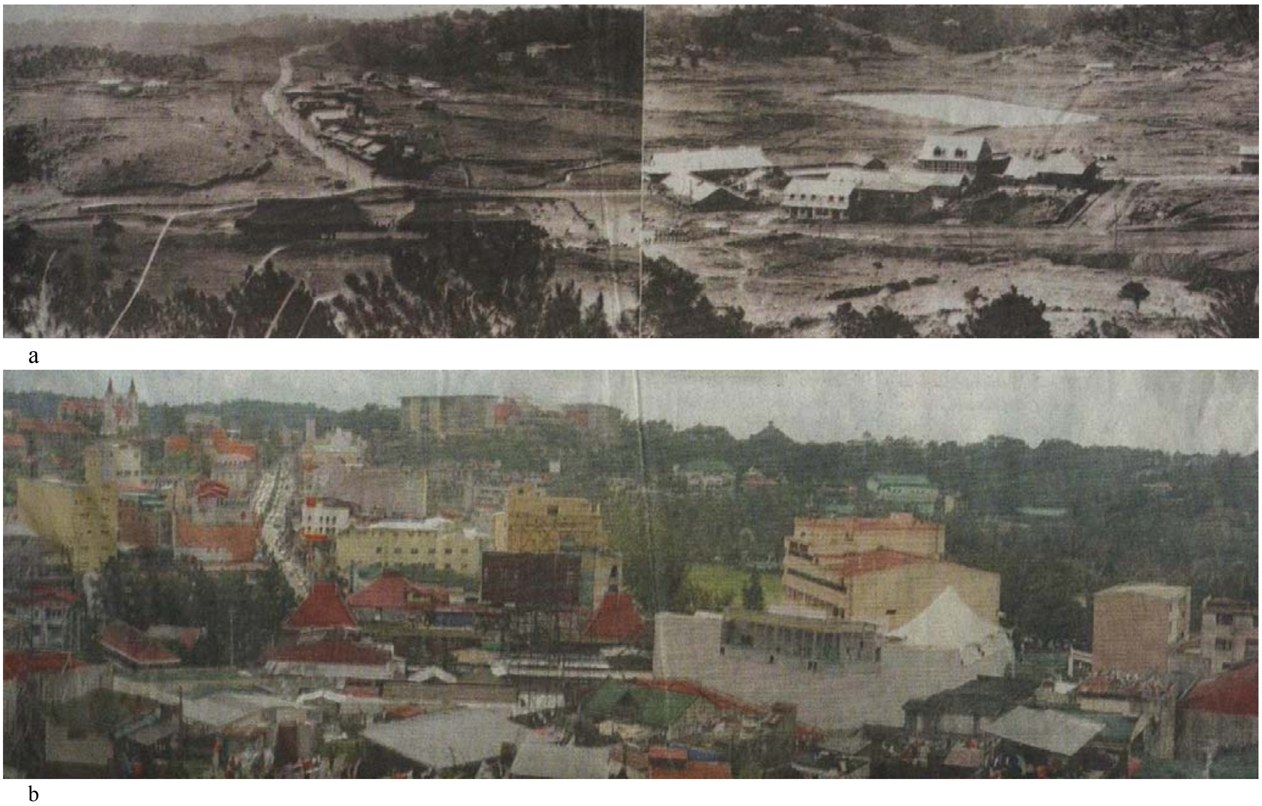

Fig. 3 Baguio in 1914 (a) and Baguio 2007 (b)

Baguio is now a centre for education, tourism, industry, health services, regional government, commercial trading and employment. All in all, over one million people live, work, study and visit Baguio yearly. With such number of people staying on a relatively small land area, the City is faced with the challenge of sustaining its projected development, rejuvenating and managing its increasingly deteriorating environment, and at the same time keeping it a safe and peaceful place to stay. Fig. 3 eloquently shows the extent of physical development that had happened in the CBD of the City in a span of ninety-three (93) years.

To investigate the relationship of crime and the physical environment, data consisting of a total of 2,632 reported crime incidents over a period of four (4) years (2004-2007) were collected from the Baguio City Police Office (BCPO). Since each crime was uniquely identified by an address, systematic and exhaustive ground surveys were conducted and each of the addresses was visited and "geocoded" with handheld GPS units. Fig. 4 shows the step-by-step process adopted by the researchers in geocoding each crime address. The last step in this process was the uploading of all the recorded x and y locations in a GIS software (Geomatica Ver. 9.1.7) for visualization purposes. Data verification was done by using a satellite image as well as road, land use and police jurisdiction basemaps of the City as background features.

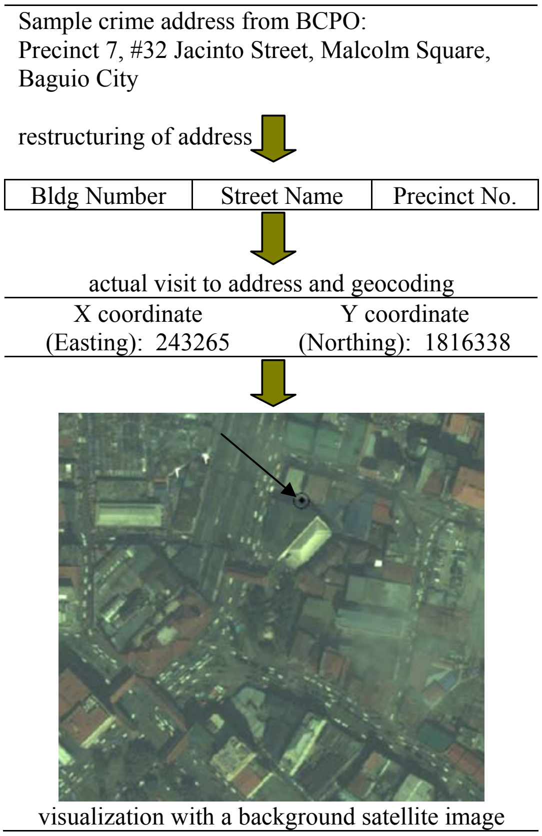

Fig. 4 Geocoding process

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Initial classification and comparative prediction of crime types according to land use was performed with CHAID to check which areas in the City were most exposed to crime. A hypothetical probability was generated and the independent variable used is 'crime type'. Through the classification tree procedure (CTP), the interaction of crime type with two major land use classifications (residential and non-residential) were determined. Although there might be limitations to the use of the CTP and CHAID, it however was the most responsive statistical tool given that most of the data generated from the BCPO National Crime Reporting System (NCRS) forms were nominal or categorical.

Centrographic statistics using the standard distance circle and mean center algorithms of GIS were then employed to geographically visualize the spatial locations and distributions of crimes in the City. This procedure of moving back and forth from GIS to CHAID was adopted in order to confirm and supplement the findings of one method to the other.

To identify the crime hotspots, kernel density estimation using CrimeStat III (a freeware crime statistic and analysis software package which can be used in conjunction with most GIS softwares) was used. The computed hotspots were displayed and visualized over a road map of the City in order to derive specific addresses. By so doing, detailed field observation and analysis with photographic documentation of the hotspot addresses and their surrounding environment was performed by visiting each site. An environmental inventory was generated. The physical attributes which were observed are grouped into four (4) classifications as shown in Table I.

TABLE I
ENVIRONMENTAL INVENTORY OF PHYSICAL ATTRIBUTES

PHYSICAL ATTRIBUTE	ATTRIBUTE CHARACTERISTICS
1. Building Design	Features that offer natural surveillance, delineation between public and private space, proximity of sites to well-used locations [41], [42].
2. Land Use and Circulation Pattern	Boundary characteristics, land uses, vehicular and pedestrian patterns that may encourage or discourage different types of crime [43]
3. Territorial Signage	Signs of caring and proprietorship that signals to users that the owners care and are vigilant to what happens there [44]
4. Physical Deterioration and Disorder	Signs of incivility and physical deterioration which are contagious, stimulating and attractive to potential offenders [45].

IV. ANALYSES AND RESULTS

Fig. 5 shows a model of a decision tree output for 2007. The parent node indicates that the crimes of theft, robbery and physical injuries are most often committed. The researchers observed that theft consistently garnered one-third (or 31.1%) of the total crimes for the years 2004 to 2007. The other more often occurring crimes were physical injuries at 29.4% and robbery at 10.4%. The child nodes indicate that crime types can not be generalized as happening to all land uses but they occur to specific uses. *Land use can thus be used as a predictor of crime*. While theft is the overall most often committed crime in the City, residential areas experienced more of physical injury crimes while non-residential areas had more of theft. CHAID predicts that the probability of theft being committed in non-residential areas is very high varying from 85.8% to 93.7% as compared to residential areas at 24.6% to 33.6%. The non-residential areas were identified as the CDB of the City. Overall, the most often committed crimes of theft, robbery and physical injuries were commissioned within the CBD.

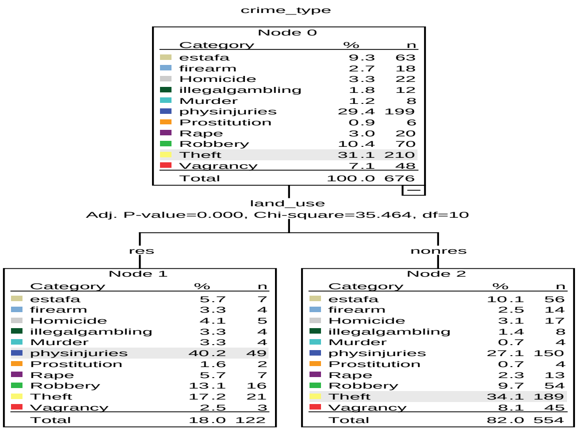

Fig. 5 Decision Tree Output, 2007

Fig. 6 shows that crime concentrations had moved yearly as indicated by the centers of the circles. The movements from center-to-center averaged at 129.20 meters but these centers had stayed within the CBD. The circles likewise show that the spatial concentration of crime from the years 2004 to 2007 had maintained an average radius of 1107.03 meters which are also within the boundaries of the CBD.

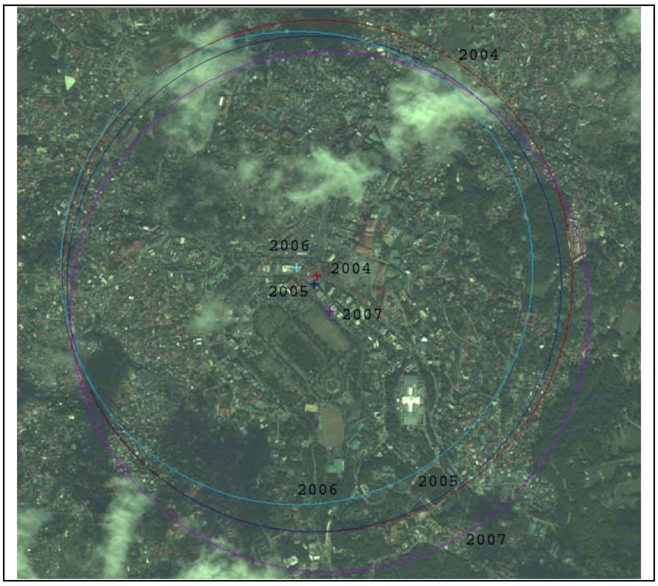

Fig. 6 Clustering of crimes

The BCPO posts a high yearly crime solution efficiency averaging at 95% but the evident recurrence and concentration of crimes at a specific area show that a strategy from catching criminals to understanding crime in the context of the physical surroundings where they occur may be necessary.

Having established that crime can be correlated to land use and that clustering is evident, the researchers moved on to defining their unit of analysis to a scale defined by specific high crime addresses and the immediate neighborhoods surrounding them. Hotspot maps were thus generated.

The resulting hotspot maps, as shown in Fig. 7, 8, and 9, indicate that the crimes of theft, robbery, and physical injuries have occurred within a number of select places in the CBD over the four-year period. Other crimes (e.g. murder, rape, etc.) were comparatively few and too dispersed to provide usable and place-specific hotspot computations. The hotspot maps present color gradients which indicate the frequency of occurrence of crimes, from hotspots (dark) to cool spots (light). The standard deviation ellipses indicate the positions and the directions toward which crimes have a tendency to be patterned. The photographs of the hotspot addresses capture the design and milieu of the place.

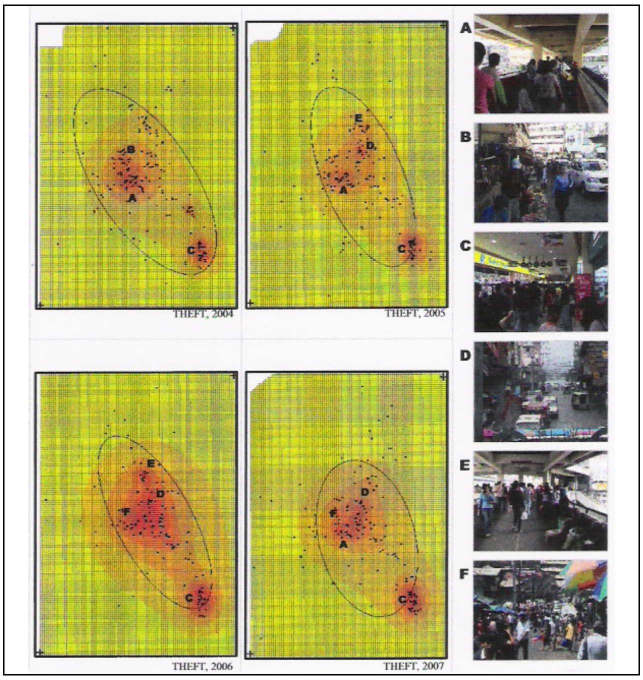

Fig. 7 CBD theft hotspots

Six (6) addresses were visited and analyzed for theft, eight (8) for physical injuries, and four (4) for robberies. The standard deviation ellipses for physical injuries and robberies have more or less maintained a north to northwest direction which generally followed the City's commercial-market-recreation crime activity axis. Theft, on the other hand, exhibited a strong northwest direction which follows a mall-commercial-market crime activity axis.

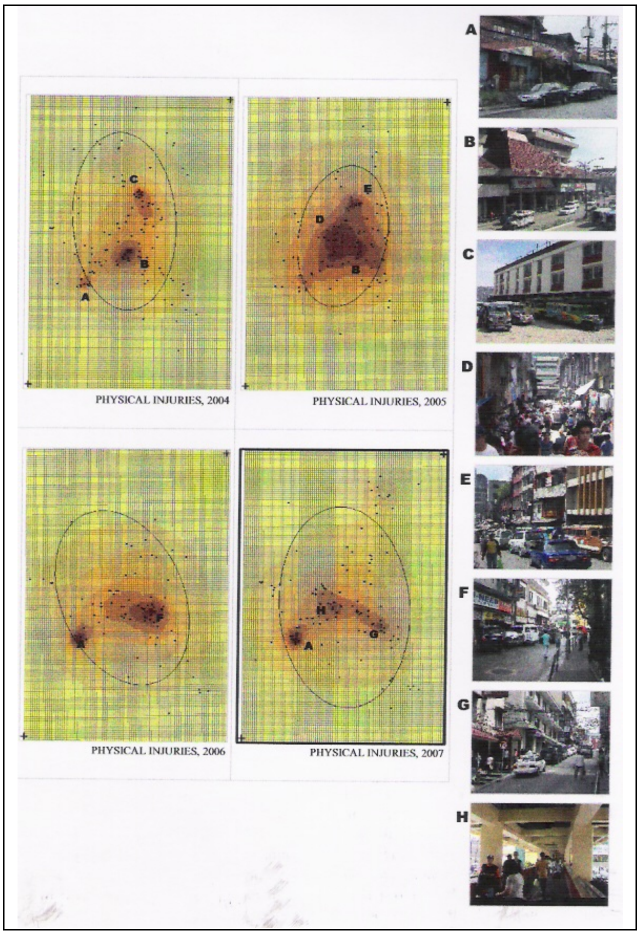

Fig. 8 CBD physical injuries hotspots

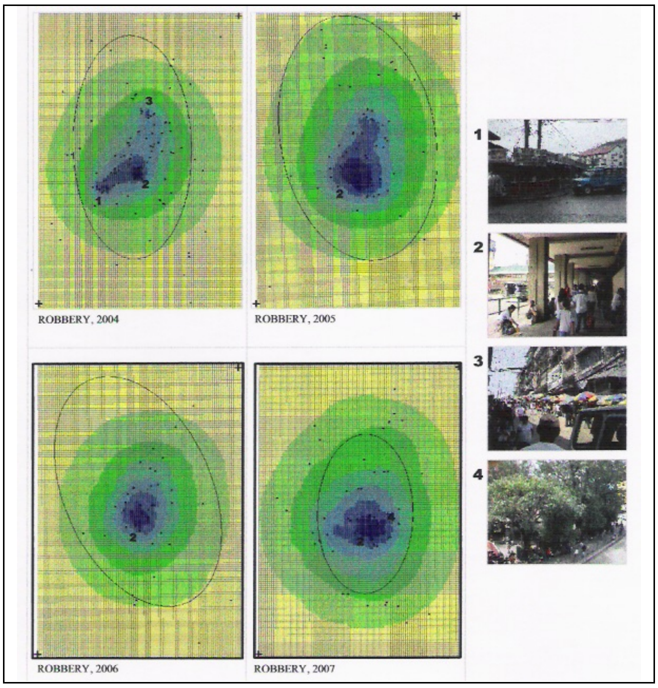

Fig. 9 CBD robbery hotspots

The environmental inventory is presented in Table II. From direct observation, the researchers noted the physical attributes that were present in the hotspot addresses.

TABLE II
ENVIRONMENTAL INVENTORY

Attributes	Theft	Physical Injury	Robbery
BUILDING DESIGN – in terms of use			
Open air commercial: market	2/6	1/8	1/4
Open front commercial	1/6	2/8	1/4
Retail "big box": mall, shopping center	1/6	1/8	1/4
Closed front liquor stores, bars, eateries		2/8	
Open front liquor stores, bars, eateries			1/4
BUILDING DESIGN – in terms of pedestrian access			
Indoor access routes: elevators, escalators, stairs, hallways	1/6		
Outdoor access routes: sidewalks, overpasses	5/6	8/8	4/4
BUILDING DESIGN – in terms of features			
Possible entrapment zones (railings, recesses)		6/8	2/4
No public phone access	2/6	5/6	3/4
Inadequate night time lighting		6/8	3/4
Poor visibility from surroundings	6/6	8/8	4/4
Possible hiding spots (big columns, large plantings,)		2/6	2/4
Narrow pedestrian access routes	4/6	7/8	2/4
Wide pedestrian access routes	2/6	1/8	2/4
LAND USE AND CIRCULATION			
Nearby jeepney and bus terminals	6/6	8/8	4/4
On-street parking	5/6	5/8	2/4
Heavy pedestrian traffic	6/6	2/8	1/4
Moderate pedestrian traffic		6/8	3/4
Heavy vehicular traffic	6/6	2/8	
Moderate vehicular traffic		6/8	4/4
Nearby alleys, street intersections	5/6	7/8	4/4
Nearby liquor stores, bars and eateries	3/6	7/8	4/4
Nearby open parks		1/8	1/4
TERRITORIAL SIGNAGE			
No visible guard, police officer, security camera	5/6	6/8	4/4
PHYSICAL DETERIORATION AND DISORDER			
Deteriorating building stock, run-down establishments	5/6	6/8	2/4
Litter, graffiti	5/6	8/8	4/4
Vagrants, vendors	5/6	8/8	4/4

Note: 6 addresses were visited for theft, 8 for physical injuries and 4 for robberies. The numbers indicate the frequency of occurrence of a physical feature against the total number of addresses visited for each crime type.

The correlation studies show that certain urban forms and designs may influence the occurrence of specific crime types. Theft occurs more on areas with open-air commercial activities, on narrow outdoor sidewalks and overpasses which experience crowding due to heavy pedestrian traffic. The theft places further occur in places with deteriorating buildings and run-down establishments. Heavy vehicular traffic, on-street parking for private vehicles and the presence of nearby terminals for public utility vehicles (called "jeepneys") lend to the crowding of the theft areas and at the same time obstruct the view from the surrounding areas. Scattered litter, vagrants and vendors likewise abound. The mall, which is a new development in the City, is a theft hotspot which offers contradictory attributes since it has large glass open frontages and good aesthetic design. Theft in the mall happens at the crowded hallways and lobbies where escalators and elevators are situated. Crowding, especially in constricted spaces with minimal or no guardianship seems to be a major factor for this type of crime.

In the case of physical injury crimes, the presence of nearby liquor stores, bars and eateries seem to influence their occurrence. Elevated night time occurrences were noted and usually at addresses where there is poor lighting, absence of public phones, and on narrow sidewalks and overpasses. Moderate pedestrian and vehicular traffic were observed especially at night time. The hotspots are near to jeepney and bus terminals. Dark alleys and the presence of parked vehicles afford poor visibility from the surroundings. Majority of the hotspots are located in the older and run-down buildings where guardianship and maintenance are lacking. In the case of the newly refurbished buildings, large columns on the arcaded sidewalks provide good hiding places and the provision of railings entrap possible victims. Usually, there were only two possible entry and exit points which are situated at the far ends of the property.

For robberies, open front commercial areas as well as open front liquor stores, bars and eateries were the preferred locations. Buildings with design features that afford hiding and entrapment (columns, railings, trees and bushes, seating, alleys) were observed. The absence of public phones, good lighting and guardians were likewise detected. Offenders seemed to prefer outdoor places with poor visibility from the opposite side of the street since the view is obstructed by the presence of high bushes and trees in the park as well as parked vehicles. Jeepney terminals were noted to be situated nearby. The streets experience heavy to moderate pedestrian traffic and moderate vehicular traffic. Vendors and beggars were observed to abound in the hotspot places.

The "heart" of these crime activities is the market. Since the area exhibits a very mixed land use, deteriorating building stock, abundance of jeepney terminals, high pedestrian and vehicular traffic volume, and an almost 24-hour operation, this place is a persistent crime hotspot be it theft, robbery or physical injuries. The apparent loss of control and management due to the sheer volume of activities may have contributed to the physical breakdown and worsening of the area. Offenders seem to favor areas of this type where guardianship and physical care have clearly been neglected. The "broken windows" thesis of Wilson and Kelling [45] is thus supported. The presence of dilapidated buildings, scattered litter, graffiti, illegal vendors and beggars evidently demonstrate the relationship of physical and social incivilities to crime.

Land use, as earlier stated, can be a determinant of crime type. It was shown that bars, liquor stores, and eateries may act as crime generators especially in the case of physical injury crimes. Theft and robberies are strongly observed in commercial and retail areas where people converge.

Street characteristics such as on-street parking, vehicular and pedestrian traffic also seemed to affect crime. Theft favors crowding whereas the crimes of physical injuries and robberies stay in moderately used areas. The presence of parked vehicles contributes to obstruction and poor visibility. The siting of jeepney terminals strongly gives a possible strong influence on all three crimes. Since the Baguio CBD is where most of inter- and intra-city public transportation terminals are situated, they may, aside from bringing a large amount of people into the CBD, act as offender "importers". The adjacency of undesirable establishments (bars and liquor stores) and the apparent laxity in maintenance and security at the terminals themselves may further alleviate criminal opportunities. Marcus Felson [44] had argued that criminals and victims find the shortest route, spend the least time, and seek the easiest means to accomplish something. The terminals may help ease the traveling and escaping of offenders. The researchers developed "journey to crime" maps by plotting the relative addresses of offenders and the CBD victim locations as shown in Fig. 10, 11 and 12. It is interesting to note that while a number of the offenders live adjacent or within the CBD, majority are from beyond the CBD limits.

V. Conclusion

The ecology of crime is true in Baguio City. Crime is not only about offenders and victims may also be about places. This study has shown that knowing and understanding the patterns and locations of crime through automated geographic visualization and data mining techniques may be effectively used in consonance with environmental renewal and rejuvenation objectives. The GIS capability of allowing analyses at different spatial scales coupled with its geo-statistical algorithms to compute for hotspots show that crime is place-specific. It further indicates that crime cannot be generalized and that the usual practice of making inferences about individual offences based on aggregate data (e.g. crime per precinct land area, crime per population, police to population ratio) will fall foul of the ecological fallacy[1].

Further, the study has shown that there are places which experience high criminal activities even if there are other places in the City which offer similar land uses but experience lesser crime. The researchers venture to explain why there are hotspots as well as cool spots: physical design attributes and milieu may influence crime.

[1] An ecological fallacy occurs when statements about individual events are made based on aggregate data for a group.

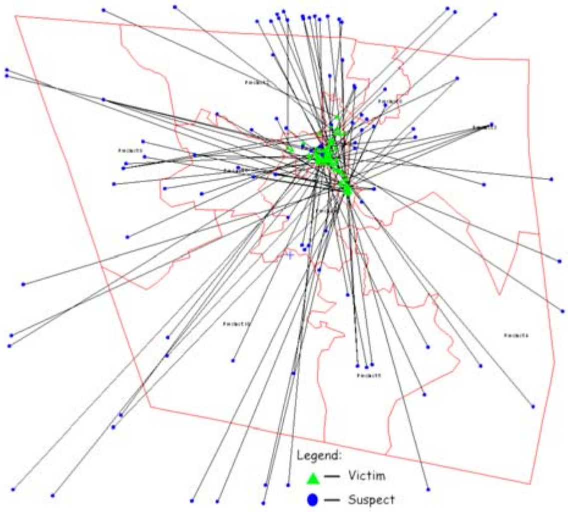

Fig. 10 Journey to crime map for theft

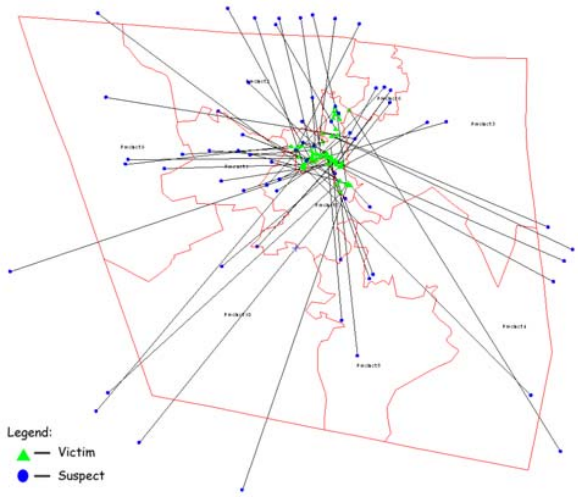

Fig. 11 Journey to crime map for physical injuries

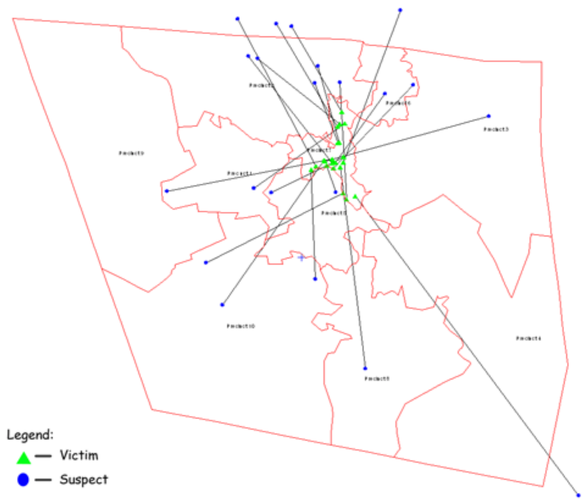

Fig. 12 Journey to crime map for robbery

The appeal of technological solutions, like geographic visualization with GIS and data mining, may bridge the gap between and among different fields of studies. This study has shown that the acquisition of new tools and technologies as well as the acquisition of new paradigms (the relationship of crime, geography and environmental design, in this case) may be a sign of maturity in the development of global professional communities. Information is indeed, power.

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