Analyzing Socio-economic and Geographical factors for Crime Incidents using Heat maps and Hotspots

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ABSTRACT

Spatio-temporal data mining techniques are used for crime analysis for their knowledge oriented and meaningful visual representation of crime incidents. Visual representation of crime patterns assist analysts with in-depth understanding of crime behavior with time and location. The representation can be made more knowledgeable and perceptible by incorporating details of socio-economic factor and areafis geographical information providing insights to features that actually play role in certain crime pattern. To analyze the impact of these factors, two of the best density calculation clustering techniques i.e. Heat Maps and Hot Spots analysis are performed for Crime Against Person and Crime Against Property. The analysis demonstrated that Crimes Against Persons are more frequent in rural and sub-urban areas with mostly low socio-economic conditions; whereas, Crimes Against Property are mostly in commercial areas with mix socio-economic conditions.

CCS CONCEPTS

•Theory of computation →Unsupervised learning and clustering;

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1 INTRODUCTION

Crime Analysis employs data mining and inferential statistical analysis with crime incidents data, textual criminal reports and graphical information. It helps in developing an appropriate strategy providing an insight to understand criminal activity. Additionally, mapping crimes on geographical maps using applications of GIS (also referred as GI Science) i.e geographic information collection, storage, analysis and representation can improve perceptibility and understandability of crime incidents. GIS is a relatively new field in data mining and has gained massive popularity in studies where environmental factors, time and location can affect the set of incidents [19].

GIS has recently been applied for identifying future patterns of crimes using hotspots identification to help Law Enforcement Agencies (LEAs). Hotspots are the areas where frequency of crime occurrence is larger than rest of the areas. Accurate prior identification of hotspots can help LEAs to engage forces in these areas in a better and more effective way to handle the crimes and lessen the crime rate. There are works reported where hotspots for 'burglary' are identified by performing classification and spatial clustering algorithms [12]. Similarly, spatial analysis has been applied to find hotspots for major crime types [14], [7], [20] and [2]. Hotspot identification has been useful in providing better understandability of crime incidents with respect to identifying hotspots and cold spots for different crime types. However, crime analysis can be made more informative by incorporating other external factors as well with crime data. For instance, mean temperature of a day can be used to find out how crime tend to vary during high and low temperature.

Many empirical studies have also suggested that environmental factors influence criminal activities for examples, Cohen and Felson [5] presented a routine activity theory which states that a criminal activity to occur concurrently at one place require three things (1) presence of motivated offender (2) presence of suitable target and (3) absence of Law Enforcement. Similarly, socioeconomic factors such as income rate and employment rate etc affects crime incidents. Goldstein [8],Roncek and Bell [18], Harries [11] and Anselin et al [1] researched on socioeconomic factors to find out relationship of criminal data with the factors. Other demographic characteristics such as rural, urban or sub-urban area, youth rate, number of institutions (business and utility) in an area etc also affects the type of criminal activities and therefore, can provide in depth information about crime variation and perception about the reasons behind formation of hotspots and cold spots. [21],[6] and [17] performed analysis of crime data with land categories such as *commercial, residential, industrial, institutional, recreational, or transportation area* and found that crime concentrates in commercial and recreational areas. The information when amalgamated with

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GIScience for spatial analysis can provide more understandability and perceptibility.

In this study, we performed extensive experiments on a number of different types of features such as geographical, demographical and socio-economical and analyzed them using Hotspot and Heatmap analysis. The crime data from a district of over 30 Million population for year 2012-2014, having varied geographical, demographical and socio-economic conditions is used. Crime incidents of two major crime types is analyzed i.e. *Crime Against Person* and *Crime Against Property*. Socioeconomic features (low income, high income, mix) and land categories (*commercial, residential, industrial, institutional, recreational, or transportation area*) is incorporated into the dataset and analyzed using heatmaps and hotspot analysis. Heatmaps are generated using kernel density function and hot spot analysis is performed by Getis-Ord G* algorithm. The analysis provide evidence of the fact that different crime type tend to behave differently with respect to socioeconomic information of an area and land category. The pattern of crime incidents i.e. crime dense areas in case of heat maps and areas of statistical importance in case of hotspot analysis helped to draw conclusion about how these added features in dataset are determining the concurrent crime behavior for two crime types, i.e. *Crime Against Person* and *Crime Against Property*. A total of 30,123 crime incidents reports are used for analysis.

2 RELATED WORK

Crime analysis involves extracting the patterns of different types of crimes from reported incidents. These patterns are then used by law enforcement agencies to anticipate the particular types of crime incidents in different geographical regions using crime prediction and deploying resources more effectively. Various environmental factors influence the crimes as it has been reported in a number of studies that various social, economic, environmental and geographic factors can directly be linked with different types of crimes. For example, Goldstein [8] gave the concept of problem oriented policing which seeks the underlying causes of persistent criminal activity. In another study, Roncek and Bell [18] indicated that alcohol consumption contributed to increased levels of violence (crime against person). Harries [11] noted that Census Bureau information, national crime information like the probation and missing persons lists as well as the sex offender registry, and volunteered information from microblogging and social networking services are other important features that can dig facts about crime activity. Anselin et al [1] indicated that crime was correlated with poverty and a lack of social control.

Frequency of occurrences of different types of crimes has been studied using clustering techniques with GIS. Bruce [4] mentioned that the key crime aspects are crime type, location, time, MO and suspect description that can be used for analysis. Geographical association with crime incidents is key aspect of tactical analysis. In order to define geographic association among crime incidents, two sets of spatial statistics measures are used; spatial autocorrelation and distance analysis. Both methods have similar goal, i.e. to calculate the measure to which incidents are, or not, clustered [13]. Auto-correlation analysis determines the relation with statistical significance measure. Distance analysis work on point data rather than polygon data to find out clustered relationship between points. Both techniques have other measures depending upon the technique used for analyzing spatial patterns and type of patterns being formed.

Table 1: Spatial Clustering Techniques with Methodology and Possible Results

Technique	Methodology	Resultant Pattern
Fuzzy Logic	Search points in user specified search radius	Multiple overlapping hotspots
NN Hierarchical Clustering	Search points closer to search radius	User specified clusters formation
Risk Adjusted KNN	Search all points within data	Clusters formation via user specified denominator i.e. population etc
Anselin Local Moran Statistic	Search points via polygon creation by user	Find hot zone areas
K Partitioning Statistic	Search points within target areas	User specified hotspots formation
Spatial Temporal Clustering of Crime	User specified search radius and number of points per cluster	Clusters formation said to be hotspots

Spatial analysis of criminal record with hotspot analysis is a well-studied area. Researchers have performed analysis with different advanced algorithms such as fuzzy logic, risk adjusted K nearest neighbor, Hierarchical clustering, Anselin local Moran statistic, and Spatial-temporal clustering to create hotpots for different crime types. All techniques tend to perform one basic task i.e. cluster formation of crime incidents with different underlying methodology. 1 gives detailed information about the algorithms. [13] The algorithms either work on polygon data or point data with enhancements such as user defined search radius or target areas or even number of points per cluster. Mahendiran [14] performed spatial analysis to identify hotspots for major crime types by risk adjusted clustering, hierarchical neural network clustering, local Moran statistic and Bayesian belief networks. The model provides insight to which crime type is prominent among the years and in which regions. Similarly, Eck [7] identified hotspots for crimes by using mean, standard deviation distance, standard deviation eclipse and data clustering. Shekhar [20] used point location, Hierarchical partitioning, density and clumping techniques to find hotspots for burglary crime type. Baboo [2] identified crime count for theft and burglary by performing density based spatial clustering, classification and outlier detection.

Brown, Liu and Xue [3] suggested that criminal incidents are random events in space and time and proposed a model based on transition density to identify crime patterns. Grubesic and Mack [9] discovered the utility of statistical techniques for identifying and comparing the spatiotemporal characteristics of different crime types. Hadi Fanaee [22] used ST-DBSCAN as a spatiotemporal

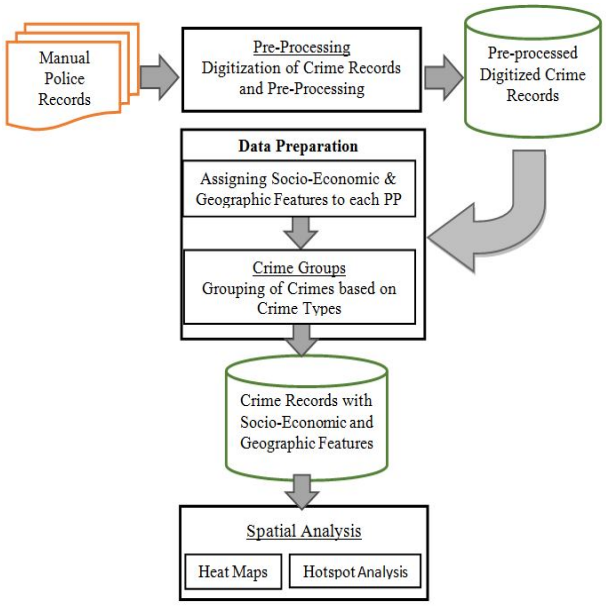

Figure 1: System Flow: Spatial Crime Data Analysis using Heatmaps and Hotspots

distance function with spatial and time threshold to discover the spatiotemporal behavior of events. However, few researchers have performed analysis on combining the work i.e. spatial analysis of crime incidents with external factors. Justin and Valerie [21] made novel use of density function to calculate crime rate along city boundaries and edge. They deduced that 64% of crime rate is higher on edges than interior. Keith Harries [10] used kernel density function for Baltimore country to find out how crime changes with social and physical circumstances. McLafferty [15] also identified crime dense areas through kernel smoothing function. Homicide variation for Chicago city were identified by Jaffrey [16] in 343 neighborhood. The finding explained that spatial dynamics coupled with neighborhood inequalities in social and economic capacity are resulting in urban violence.

Our paper provides the detailed analysis on crime dataset that has been gathered for a district from a developing country where variance in socio-economic and demographic opportunities can play major role in influencing crime of different types. Our study reports the affect of these factors on two major types of crimes, i.e. Crimes against Person and Crimes against Property.

3 METHODOLOGY

The methodology used in the analysis can be divided into three major parts; (i) Data Collection and Preprocessing (ii) Feature Extraction (Data Preparation) for Analysis and lastly (iii) Spatial Analysis of data with *Heatmaps* and *Hotspots*. The overall methodology is illustrated in System diagram 1.

3.1 Data Collection and Pre-Processing

The major bottleneck at start of this work that we faced was unavailability of crime reports in digitized form. Data has been maintained manually in registers. Therefore, the first task was to digitize this huge data. In order to accomplish this, data for Rawalpindi city is collected and digitized from manual crime reports. Collected data consists of following attributes: *Date of Crime incident, Date of report, Police Station, Sub-area, FIR no and Crime Phrase.* A total of 50236 records are digitized. At this stage, only brief data (as shown in Table 2) is collected and detailed textual report is not considered.

Table 2: A Snapshot of Crime Records Data After Pre-Processing

Date of Occurrence	Police Precinct	Sub-Area	Crime Type
3-Jan-2013	SB	GPO	Theft
3-Mar-2013	AP	Judicial Colony	Car Theft
29-Aug-2013	WR	Shalay Valley	Murder
3-Nov-2013	NT	B Block	Woman Assault
9-Dec-2013	SA	6th Road	Hurt

After digitization, the data is cleaned by performing following steps: Removal of redundant attributes, for instance, Date of crime incident is only kept while data of FIR is removed; FIR numbers are also removed as they cannot play any role in spatial analysis. Police station are assigned symbols and phrasal crime description is converted to standardized crime type. Cleaned and processed data is shown in Table 2. In this way, crime data for Rawalpindi district is recorded with total of sixteen police precincts.

3.2 Feature Extraction

Features extraction is performed in three phases. These extracted features are then linked with pre-processed data (as shown in Table 2. In first step, the features related to spatiality are added. They include Longitudes and Latitudes of crime incidents.In second step, the crimes are grouped considering similar crime types and finally, Geographic and Socio-economic factors are added to data. Details are described below:

(1) *Latitudes and Longitudes*: First feature to incorporate into data are latitude and longitude of police precinct sub-area. The points are important for accurately drawing crime incidents on map. Although sub-areas can also draw points on map but due to same names of streets, markets and roads, points cannot be drawn accurately on map.
(2) *Grouping of Crimes*: Crime incidents that fall into the categories of *Crime Against Person* and *Crime Against Property* are grouped together. Crimes like murder, hurt, attempt to murder, kidnapping, woman assault and suicide fall into category of *Crime Against Person* whereas crimes such as theft, robbery, car theft and burglary were grouped into category *Crime Against Property.*
(3) *Geographic and Socio-Economic Factors*: Rawalpindi city consists of 16 police precincts with different geographic and socio-economic status. For example, some regions fall in commercial area, few in residential area, few have utilities (governmental departments) and few are mostly containing transportation facilities such as bus stops. Based

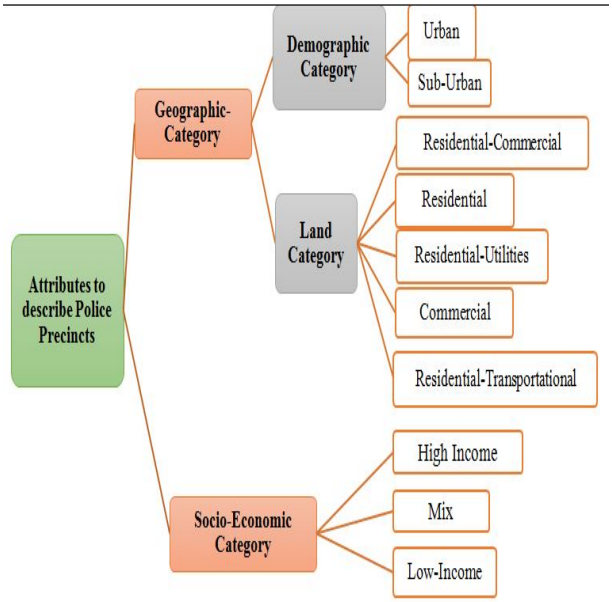

Figure 2: Attributes to describe socio-economic and geographic properties of Police Precincts

on these differences, different attributes are prescribed to describe various regions. The major attributes are: Geographic Category and Socio-Economic Category. The Geographic Category is then further divided into Demographic Category and Land Category.

The rationale behind assigning different values of Land Category to different regions is summarized in 3

All the precincts in Rawalpindi city are categorized into different groups according to their demographics using rationale provided in Table 2. Table 4 provides complete detail of 16 precincts providing their geographic and socio-economic category. Hotspots for crime can be found by simply drawing incidents on map but in particular, the ***socio-economic situation*** is analyzed in detail here as it can dig deep into facts that how income rate and geography of an area affect crime rate. Providing insights to how particular landmarks attract particular crime and how income rate change crime behavior with its values of high, mix and low. The information can aid law enforcement in more precise way to formulate strategies for crime control by laying focus on specific area.

3.3 Spatial Analysis of Data

Heat Maps: Heat mapping is a method of showing the geographic clustering of criminal activities taking place in a given location. It is a way of visualizing locations on map so that patterns of higher than average occurrence of things such as crime activity can be viewed. The data used in the study is crime incidents of *Crime Against Person* and *Crime Against Property* of Rawalpindi, for year 2012-2013. The idea behind the research is to create heat maps for two types of crime highlighting major areas affected most with particular crime type and giving additional information about areafis land characteristic and income rate.

Table 3: Rationale behind assigning values of geographic category to Police Precincts

Geo-graphic-Category			Rationale
Demographic Category	**Land Category**	**Symbol**	
Urban	Residential	U-R	Purely Residential area with few local shops/markets.
Urban	Residential Commercial	U-RC	Residential area with shopping malls and eateries.
Urban	Residential Utilities	U-RU	Residential area, with hotels, offices, parks, institutions and hospitals.
Urban	Residential Transportation	U-RTp	Residential area with major bus stands and low grade hotels.
Urban	Commercial	U-C	Commercial area with negligent proportion of residential area.
Sub Urban	Residential	SU-R	Residential area with low economic condition, illiteracy and culture of keeping arms

Table 4: Police Precincts with possible values of Geography and Socio-Economic Factors

PP	GEO	So-Eco	PP	GEO	So-Eco
CN	U-C	Posh	WR	U-R	Posh
AP	U-RC	Posh	WK	U-R	Low
City	U-RC	Mix	SB	SU-R	Low
NT	U-RC	Posh	RC	U-RU	Posh
CL	U-RU	Posh	MG	U-RU	Posh
GM	U-R	Low	SA	U-RU	Mix
RT	U-R	Low	NB	U-R	Low
PW	U-RTp	Mix	BN	U-R	Low

Heat maps use kernel density or line density function to create raster of high density areas and low density areas. We used kernel density function for heat map creation. It assumes a smoothly curved surface where all crime incidents are mapped. The value is highest at the location of crime incident and slowly weakens as it moves away from the incident and finally reaches 0 at search radius distance from the point. The density at each output raster cell is calculated by adding all kernel surfaces where the overlay raster cell center. It finds out default search radius for density calculation by calculating mean, median and standard distance of weighted distances. Steps involved are;

- Calculate mean center of all crime points
- Calculate the distance of all points from weighted mean
- Calculate the median of the distances, Dm
- Calculate Standard Distance, SD

$$G^* = \frac{\sum_{j=1}^{n} wi.jxj - \bar{X}\sum_{j=1}^{n} wi,j}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} wi,j\right)^2\right]}{n-1}}}$$

$$\bar{X} = \frac{\sum_{j=1}^{n} xj}{n}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} xj}{n} - (\bar{X})^2}$$

- Lastly, calculate search radius from measures calculated for all crime points i.e. n

$$SearchRadius = 0.9 * min(SD, \sqrt{\frac{1}{ln(2))} * D_m) * n^{-0.2} \quad (1)$$

Hot Spot Analysis: Hot Spot Analysis calculates the Getis-Ord Gi* statistic for each crime incident in a dataset. Resultant values are in form of p-value and z-scores identifying where features of high and low values will cluster. The values are calculated by considering neighbors of each feature plotted on map. Feature with a high value is not a hotspot for all cases as, for a feature to be a hotspot it is necessary that it is surrounded by feature of high value as well. To calculate z-scores difference between two features set is calculated, and if difference is large enough as compare to result of random chance a statistically significant z-score results. Calculations involve:

Where xj is the attribute value for feature **symbols** is the spatial weight between feature i and j and n is equal to the total number of features in dataset. Mean of all weighted distances and standard deviation is calculated by:

Gi* statistic actually returns z-score for each feature in the dataset. The larger the z-score the more clustered are incidents of high value (hotspot) and the smaller the z-score the more clustered incidents of low value (cold spot) result. Z score ranges from -1 to 1 indicating place of a particular point in dataset relative to calculated mean, with z=0 point is equivalent to data mean, z¡0 is a value less than mean and z¿0 is a value greater than the mean.

4 RESULTS

Heat maps are generated in two ways; (i) without boundary where points of incidents are considered to show area of high density and area of low density and (ii) within boundary line to calculate density. The second technique highlighted only areas of above than average density points and overlooked points of low or average density. The first technique distinguishes between areas of high and low density providing better understandability of how crime rate changes with areafis geography and other socio-economic factors. However, the later technique gave clear picture of high density areas showing points of high density only. Both *Crime Against Person* and *Crime Against Property* are tested via the techniques, Fig 3 shows results of *Crime Against Person* and Fig 4 represent *Crime Against Property*.

The results for *Crime Against Person* shows that crime is disperse over the city with no specific region of high or low density. However

Figure 3: Heat maps for *Crime Against Person* with and without boundary

area of above than average density are notable with maximum density value of 30.96. The value is for darkest point in case density calculation with boundary technique. Other above average values include from 24.76 - 27.86, 21.67 - 24.76 and 18.57 fi?! 21.67 i.e. for dark purple to light purple points respectively. The case is totally different for crime against property, where regions of highest and lowest density is clearly evident. Three major regions of highest density is shown by heat maps generation. The density values for darkest (highest density area) are from 267.83 fi?! 297.59, 238.07 fi?! 267.83 and 208.31 fi?! 238.07. The least dense point has value of 0.0 fi?! 29.75, which is maximum value in case of crime against person. Heat map generated for two crime types show variation because of the crime behavior which seem to be focused to 3-4 regions in case of crime against property and scattered in case of crime against person.

Other reason is the point of discovery which we paid focus to i.e. socio-economic factors and geography of the area. Rawalpindi city as described earlier has different land categories ranging from purely residential to commercial residential or residential utilities to purely commercial. As *Crime Against Person* generally occurs in areas of low socioeconomic status, i.e. low income, low education rate, illiterate people etc. Such areas mostly fall in rural category whereas Rawalpindi city is purely urban area. Therefore, no particular crime behavior is seen here. Going in depth we still came across facts that area of high density for crime against person fall in U-R and SU-R areas with police precincts such as SB, NB, GM, BN and SA. All four precincts have low socio-economic status and fall in residential area with only SA precinct that fall in R-U area and has mix income rate. *Crime Against Property* target specific areas that either fall in commercial area or in utilities area. Heat maps show that most dense crime areas are of CN, RC, NT, City and SA police precinct. Incidents like vehicle snatching, mobile and money snatching, vehicle theft etc are common in commercial utilities area with parking places where people either park in hurry or at wrong

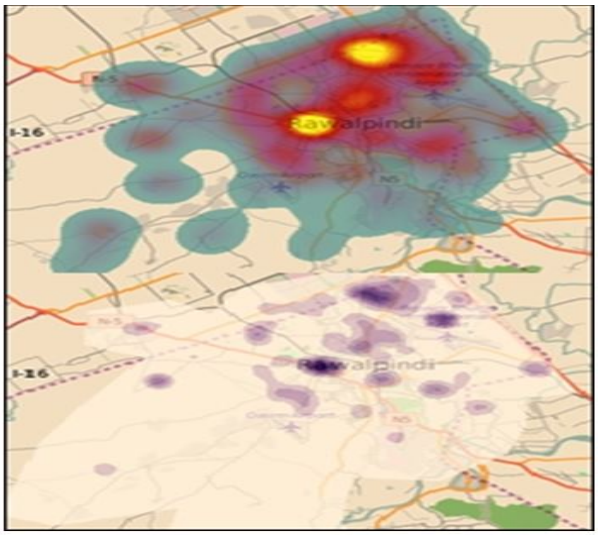

Figure 4: Heat maps for *Crime Against Property* with and without boundary

place making vehicle vulnerable to theft. Then bringing cash for shopping give fair chance to thieves for money snatching. Also these areas have high socio-economic stats i.e. posh area with high income rate making burglary and theft incidents prominent.

The results can be summarized that *Crime Against Person* have more incidents in area with low socio-economic features and pure residential areas. Whereas, *Crime Against Property* have more incidents in areas with high socio-economic factors and having land category either residential commercial or residential utilities. Table 5 show detailed description of socio economic factors, police precincts, land category and possible reason of two types of crime type occurrences.

Hot spot analysis is different from heat map generation in a way that heat maps display areas of high and low values of density crime occurrences while hotspot analysis show areas of high and low statistical importance. For an area to be a hotspot it should have points that are all surrounded by feature of high value z-score. Cold spots are areas of low statistical importance having all points of low z-score values. Whereas, points that do not show remarkable difference in z-score values are said to be non-significant. Calculations are explained in previous section. Analysis is performed for two crime types. As discussed earlier crime against person show scattered behavior with no prominent crime dense area so hotspot analysis for the crime type represented no specific hotspot and cold spot area. Rather represented a grid of non-significant values as shown in Fig 5.

Crime against property however show few hotspot areas. Grids on the upper portion of map are marked as hotspots and few are marked as cold spots at south east side of the city located at AP precinct. Other grids are of non-significance. The grids having z-score difference of above zero are marked as hotspots (red grids), below zero are cold spots (blue grids) and grids with zero difference are non-significant. Hotspots are created at NT, SA and City police precincts. The reasons for the created points are same as given in heat maps i.e. commercial residential area with high socio-economic factor.

Table 5: Crime Types with target Police Precincts and deduced reasons for crime occurrence

Crime Type	PP	So-Eco	Geo	Reasons
Crime Against Person	SB, GM, NB, BN, SA	Low Income, Mix	U-R, SU-R, U-RU	Uneducated people, no knowledge of Law, low incomed area and tradition of keeping arms commonly fight over land disputes, drunk or involved in gambling fight over money issues, hit or assault woman and kill each other on name of respect.
Crime Against Property	CN, NT, City, RC, SA	Mix, High Income	U-C, U-RC, U-RU	Posh and high incomed areas give fair chance for robbery, theft and trespassing. Commercial and utilities areas with parking places of shopping malls, hospitals, institutions, offices, parks and restaurants allow incidents of vehicle theft to occur.

The finding can aid to create strategies for crime prevention with knowledge that crime against person is prominent in areas of low socio-economic status and crime against property is noticeable in areas of high socio-economic status. The police department can plan and engage forces in the areas accordingly and formulate strategies to control crime in more efficient way. As the finding is focused on small areas of the city i.e. police precincts. Every precinct can strategize accordingly by engaging patrolling forces at night in areas with more incidents of crime against property as robbery incident occur most during nights. Similarly, areas of low economics should be improved by providing education facilities so

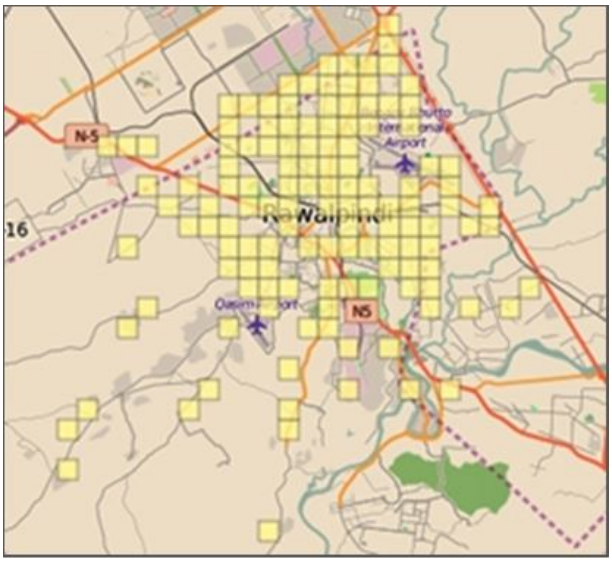

Figure 5: Hotspot analysis for crime against person

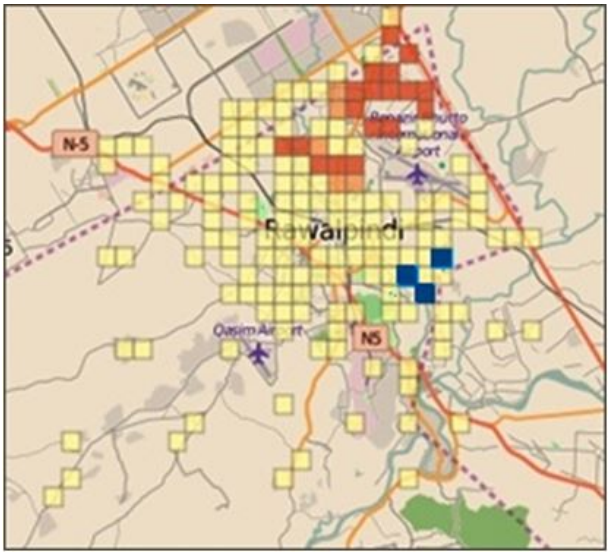

Figure 6: Hotspots for crime against property

that people should not indulge in wrong activities such as gambling, drinking, assaulting etc.

The analysis can be expanded for other crime types and also for showing prominent difference in the behavior of two crime types rural land category can be incorporated in data. The analysis however still aid in providing better understandability of crime behavior which tend to follow some pattern with external factors. The impact of Geographical category and income rate on two types of crime has been explored in the paper. Other factors like mean temperature, inflation, festivals, release of some criminal or gang, immigrants or opening of drug stores in an area can all effect crime rate in one way or another and cause rise in certain crime type.

5 CONCLUSION

The paper implemented spatial clustering techniques to analyze two different crimes behavior with the help of socio-economic factor and geographical category at police precinct level. Spatial clustering represent relationships of points with time and location. The varying nature of relationship of crime incidents with time and locations was explored by two of the basic techniques of finding spatial association i.e. heat maps and hotspot analysis. Heat maps showed clusters of high and low density crime incidents and Hotspot analysis differentiated hotspots from cold spots and also identified areas of non-statistical significance. The two types of clusters generation explored the fact that how crime is dependent on socio-economic and geographical factors. Crime against person happen to occur in purely residential areas of low socio-economic status. Whereas, crime against property targets commercial, utilities area of high socio-economic status. Spatial clustering techniques can allow law enforcement to form strategies of crime prevention by engaging their forces in areas of high victimization. With additional information of geography and land category of an area incorporated with socioeconomic status can further help Law Enforcement in knowledge driven decision making and take precautionary measures to stop crime.

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