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Analysis and visualization of crime data using GIS technology: Understanding crime patterns and distribution

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Abstract: *Crime mapping is an important method for identifying crime patterns. Crime maps are widely used to visualize spatial distribution of crime and allocating security resources. A qualified cartographic representation is essential for the presentation of the results of crime analysis, so the preparation and enrichment of crime maps requires careful obedience to cartographic principles. This article presents a combined comprehensive and understandable mapping methods and techniques for crime analysis and crime mapping for Trabzon, Türkiye. Prior to the analysis and mapping process, crime data recorded between 2011 and 2015 was reclassified. In the next stage, editing of erroneous data, standardization and geocoding processes were applied. The spatial distribution of all crimes was analyzed and mapped with the Kernel Density Estimation method. The Hexagon grid mapping technique and Hotspot method were used for visualization of spatial data and temporal trends of criminal activity. The spatial and temporal distribution of burglary and assault crimes (the most common crimes of all crimes) was mapped with these techniques. Maps also provide detailed information on crime patterns for study area, and help the police department to develop safe city strategies and reduce crime activities.*

Keywords: Crime, Crime mapping, Crime analysis, GIS, Spatial distribution

Suç olaylarının CBS ile analizi ve görselleştirilmesi: Suçun kalıplarını ve dağılımını anlamak

Öz: *Suç haritaları suçun mekânsal dağılımını görselleştirmek ve güvenlik kaynaklarını yönlendirmek için yaygın olarak kullanılmaktadır. Suç haritalama, suç olaylarının kalıplarının belirlenmesinde yaygın olarak kullanılan bir yöntemdir. Suç analiz sonuçlarının sunumu için nitelikli kartografik gösterimler gerekmektedir. Bu yüzden suç haritalarının zenginleştirilmesi ve hazırlanması sürecinde kartografik ilkelere uyulmalıdır. Bu çalışma, Trabzon ilinde suçların analizi ve haritalanması için bütünleşik, kapsamlı ve anlaşılır bir haritalama yöntemi ve tekniği sunmaktadır. Çalışma kapsamında öncelikli olarak 2011-2015 yılları arasında kayıt altına alınan suç verileri yeniden sınıflandırılmıştır. Bir sonraki aşamada suç verilerindeki hatalı veriler düzeltilmiş, veri standardizasyonu sağlanmış ve coğrafi kodlama işlemi uygulanmıştır. Suç olaylarının mekânsal dağılımı "Çekirdek Yoğunluk Tahmini" yöntemiyle analiz edilmiş ve haritalanmıştır. Suç olaylarının mekânsal ve zamansal eğilimleri görselleştirilmesi için ise "Altıgen Izgara Haritalama Tekniği" ve "Sıcak Nokta Yöntemi" kullanılmıştır. Bu teknikler ile hırsızlık ve şiddet suçlarının mekânsal ve zamansal dağılımı haritalanmıştır. Hazırlanan haritalar, çalışma alanındaki suç kalıpları hakkında ayrıntılı bilgi sağlamaktadır. Ayrıca emniyet birimleri tarafından güvenli şehir stratejileri geliştirmesine ve suç olaylarının azaltılmasına yardımcı olmaktadır.*

Anahtar Sözcükler: Suç, Suç haritalama, Suç analizi, CBS, Mekânsal dağılım

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1. Introduction

The geography of crime focuses on the relationship between crime, space, and the social environment by analyzing crime behaviors, criminals, and crime influences (Feng, Dong & Song, 2016). The crime analysis helps to identify areas with high crime rate. In addition, it ensures that these areas are shown effectively through maps, and that possible crime events are detected and prevented by using past crime events. The results of crime analysis can be considered an important part of cartographic visualization in criminal activities and these outputs are communicated through thematic maps. Crime mapping is very important for controlling and managing crime events in the space. Crime mapping contributes to policing and law enforcement by helping to understand crime patterns and criminal activity. As a general perspective, spatial analysis and crime mapping offer a number of advantages, particularly in the fields of applications such as: operational policing strategy, crime prevention or reduction, information and interaction with the community, monitoring of temporary changes in the distribution of crime and evaluation of efficiency of crime prevention initiatives (Hirschfield & Bowers, 2001; Wolff & Asche, 2019).

Hotspot maps are called an important clustering analysis technique and are the traditional method of analyzing and visualizing the distribution of crimes across space and time (Gerber, 2014). According to Ratcliffe (2004), cited in Boba (2005), a hotspot is defined as an “area with high crime intensity”. In addition to Chainey and Ratcliffe (2005), McCullagh (2006) also found different approaches to detecting and mapping hotspots (Kumar & Somashekar, 2012).

There are different techniques for generating hotspot maps. By applying Kernel Density Estimation (KDE) technique, spatial distribution of crimes and areas where the crimes tend to cluster can be identified. In KDE, greater weight is given to the events closest to the center of the radius (Eck, Chainey, Cameron, Leitner, & Wilson, 2005; Gwinn, Bruce, Cooper, & Hick, 2008; Paynich & Hill, 2010; IACA, 2013). It is important to know where crime patterns cluster in both space and time have significant effects on strategic action towards crime prevention (Glasner & Leitner, 2017). In many parts of the world, trends in crime prediction models are increasing in order to reduce crime. Gupta, Rajitha, Basu and Mittal (2012) determined the points where the crime is intense, created maps of crimes according to their types and examined the relation between the types of crime and the social factors affecting the crime with Geographic Information Systems (GIS). Gerber (2014) considered a crime prevention method using integrated KDE with twitter. Mohler (2014) used KDE for the prediction of homicides and gun crimes. Kumar and Somashekar (2012) mapped crimes and analyzed crime scenarios using Hotspot and Buffer analysis in the Tumkur region of India. Ejemeyovwi (2015) determined the spatial pattern of crime through the mapping of crime hotspot (Getis-Ord local) monitoring over a time series period of seven years of two data sets (2000-2006) and (2004 -2010) in Asaba, Delta State.

The use of GIS for crime mapping is very important for gaining deeper insights about the aspects of crimes by enabling the analysis and visualization of crime hotspots along with other trends and patterns. In addition, traditional crime forecasting systems make extensive use of historical event patterns as well as layers of information provided by GISs (Wang, Gerber, & Brown, 2012).

In this study, studies in the field of crime in Türkiye were also examined. Gurbuz and Karabulut (2007) investigated the relationship between space and crime in Adana's Seyhan district of Beşocak police center authorization area, using GIS. In the study, the relationship between space and crime was examined through buffer zones. In the study of Gurbuz, Karabulut and Temir (2013), ArcGIS was used to analyze and map the relationship between car theft crimes and space that occurred in the city of Kayseri. By using base map of Kayseri, which includes streets and block groups, several spatial analyzing techniques have been used to examine car theft structure in the study area. In another study, Eken and Kumru (2014) indicated police-judicial category crime data published in “Bizim Kocaeli” newspaper between 2011 and 2012 years on maps. In addition, they developed a web-based application that allows users to realize spatial (e.g., finding an address), proximity (e.g., listing crimes in circle with a diameter of 300 meters in manner Kocaeli University-centralized) and network analysis (finding the route the nearest police station to a crime) on these data. Aliagaoglu and Cildam (2016) analyzed the distribution of crimes by neighborhoods in Bandırma using graphics, tables and mapping methods. In the study, the relationship between crime and the factors causing was examined by using regression analysis. When these studies conducted in Türkiye are examined, it is observed that there are gaps in the spatial statistical analysis of crime and the analysis of spatial density distribution by mapping.

In this study, a spatial database model was designed to map criminal events. Density analysis of all crimes was carried out and the results of this analysis were shown as heat maps in GIS environment. One of the main purposes of paper is the creation of maps and other outputs helping perception of decision makers and people for investigating and understanding crime. In addition, hotspots of burglary and assault crime that having the highest crime events were presented to identify crime patterns and shown on the hexagon map of crimes. Hexagon grid mapping technique was used for identification hotspots of these crimes. While crime data analysis processes may be easier in well developed countries due to ready crime databases, in Türkiye crime data collection is not easy due to the lack of ready-to use and standardized crime databases and, for this reason, the GIS crime database is a new approach for Türkiye. In this study, raw datasets were enhanced to make crime geodatabase usable. These approaches and methods were considered to be a suitable model for other developing countries. Technical contribution for related scientific methods is making crime events more understandable with the help of GIS visualization approaches.

1.1 Spatial Distribution Techniques of Crime Mapping

1.1.1 Hotspot Mapping

Hotspot mapping is a widely used spatial analysis method for mapping and forecasting spatial data. The crime-mapping pattern is one of the application areas of this method. This mapping method is based on the assumption that past crime scenes are good predictors of future events (Hart & Zandbergen, 2014). Crime hotspots are areas with dense crime scenes that exhibit a nonrandom pattern in space and/or time. Hotspots are identified on the basis of the relative number of crime events. Therefore, the prediction of the critical points of crime is usually accompanied by the prediction of the crime count, and these crime counts are utilized for identifying hotspots (Hajela, Chawla, & Rasool, 2021). Hotspot mapping means finding crime patterns used to reduce crime (Gahlin & Johansson, 2014).

This method defines the spatial clustering of statistically significant high values (hotspots) and low values (coldspots). In this method, small P-value and high Z-score are significant hotspots; A small P-value and low negative Z-score indicate a significant coldspot. The Getis-Ord local stats:

$$G_i^* = \frac{\sum_{j=1}^{n} W_{i,j}X_j - X\sum_{j=1}^{n} W_{i,j}}{S\sqrt{\frac{\left[\sum_{j=1}^{n} W_{i,j}{}^2 - \left(\sum_{j=1}^{n} W_{i,j}\right)^2\right]}{n-1}}} \quad (1)$$

Here; n is the number of points in the sample, X_j is the variable value of point j, $W_{i,j}$ is the spatial weight value that gives the proximity relationship between point i and point j. The mean value of the variable ($\bar{X}$) is calculated as follows:

$$\bar{X} = \frac{\sum_{j=1}^{n} X_j}{n} \quad (2)$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j}{n} - \bar{X}^2} \tag{3}$$

G_i^* is a statistical Z-score so no other calculations are needed. The calculated G_i^* value has a normal distribution and is the Z statistic value (Gayır & Arslan, 2018).

There are different methods used for hotspot mapping. Point map, grid thematic map, Spatial Ellipses and KDE are some of the methods used. These methods often allow the visualization of areas with historical high crime concentration with the predisposition that future crimes often occur in the vicinity of past crimes (Beiji, Mohammed, Chengzhang, & Rongchang, 2017).

1.1.2 Kernel Density Estimation (KDE)

KDE is a popular hotspot mapping method. It converts point incidents to a density surface that summarizes the point distribution (Hu, Wang, Guinc, & Zhub, 2018). Areas on the surface with high density values above a predefined threshold are defined as hotspots (Hu, Miller, & Li, 2014).

In this method, a radius is determined for each point and a circular zone is created around these points. Therefore, determining the radius is one of the most important factors when using this method. In order to determine the radius value in the KDE method, the data should be analyzed statistically. The value of the radius is calculated approximately according to the mean distance between two sample data. It is obtained from the average value of the expected distance resulting from the average analysis of the nearest neighbors.

Density values are calculated by weighting the crime events according to their distance from the centers of the circles. In the method, closer events are assigned more weight than distant events, and the density is determined by the number of points falling within these circles.

It has been proven in studies that the KDE method is quite effective in terms of precision and prediction. Chainey, Tompson and Uhling (2008) compared KDE with other techniques in predictive hotspot mapping and observed that KDE performed significantly better than others (Hu et al., 2018).

When the KDE mathematical model is examined, the equation based on measuring the temporal density of crime created by Gerber (2014) is shown below:

$$f1(p) = \mathrm{k}(\mathrm{p},\mathrm{h}) = \frac{1}{Ph}\sum_{j=1}^{P} K\left(\frac{\|p-p_j\|}{h}\right) \tag{4}$$

In this equation, p is the point at which density estimation is required, h is the bandwidth parameter (controls density estimation smoothness), P represents the total number of crime types, j denotes a single crime location, K is the standard normal density function, $\|\cdot\|$ signifies the Euclidian norm, and p_j is the position of crime j.

Comparing KDE and Hotspot (Getis-Ord G_i^*) analyses results, the two methods are generally visually similar, however there is a difference between them. Kernel density function and the Getis-Ord G_i^* statistics are completely different analyses. While KDE aims to detect clusters of high values within the data, G_i^* statistic not only detects but deepens understanding of spatial clusters of the phenomena under study (Kalinic & Krisp, 2018).

2. Methods

The study consists of 8 stages: (1) Selecting the study area, (2) Obtaining crime data from the Police Department, (3) Reclassification of crime types, (4) Standardizing crime data and creating a database, (5) Linking crime data and street data (geocoding), (6) Analyzing and mapping the spatial distribution of all crimes with the KDE method, (7) Using hexagonal grid mapping technique to visualize spatial and temporal trends of burglary and assault crimes, (8) Giving the statistical results.

2.1 Study Area

Türkiye is located in the Northern Hemisphere. It has a total area of 814 578 km^2 and separated into seven geographical regions. According to the address-based population registration system, the average population of Türkiye is 75 964 660 between 2011-2015 (TUİK, 2021).

The study area is Ortahisar district, in the center of Trabzon province, in the eastern Black Sea region in Türkiye (Figure 1). Trabzon is a central city in the eastern Black Sea and located between 38˚30'–40˚30' east longitude and 40˚30'–41˚30' north latitude. The surface area of Trabzon is 4685 km^2 and Ortahisar covers almost 189 km^2 of this area. The average population of Trabzon is 761 810 (2011-2015) and 313 586 of this population is located in the center of Trabzon, Ortahisar. Approximately 51% of population of Ortahisar is female and 49% is male.

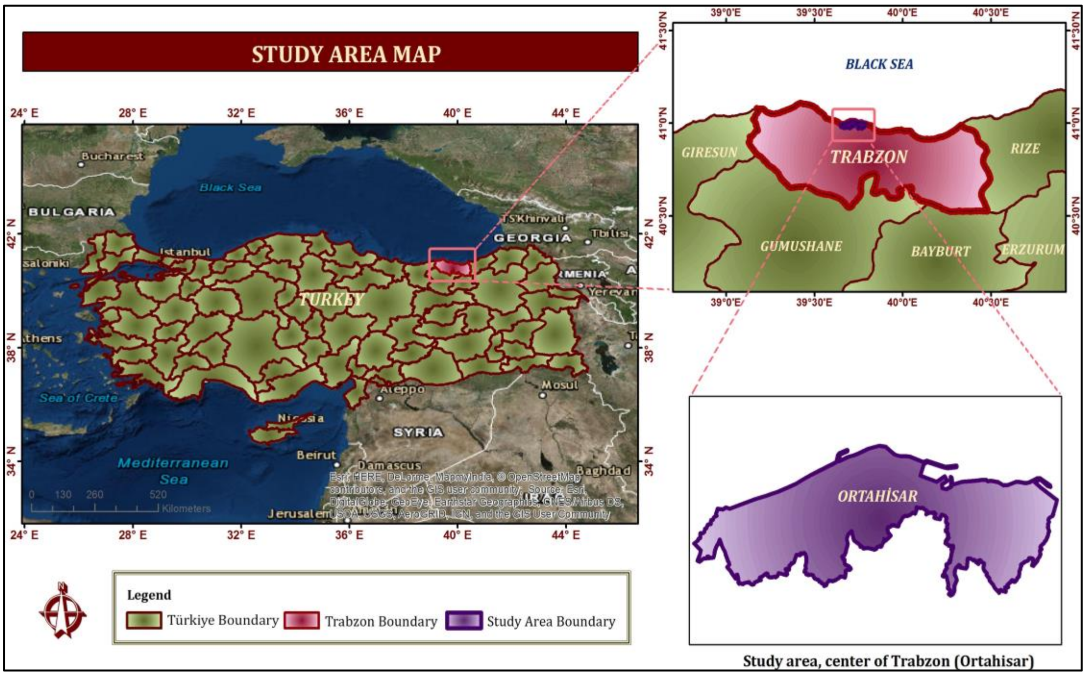

Figure 1: *Map of study area*

2.2 Database Design

A complete list of crime data was provided from Police Department of Trabzon. In addition, the authorities provided road and street networks. Between 2011 and 2015, 20,034 crimes were recorded and analyzed in this study. The data on each crime in the dataset provides information on the crime types, crime date, location of crime, the age and gender of offender. Since the crimes recorded by police involved lots of crime types and categories, crime categories were reclassified and aggregated to fourteen crime types to use in this study. The crime types and description used in this study are shown in Table 1.

***Table 1:** Crime types and descriptions*

Reclassified Crime Types	Crime Categories Recorded by Police
Burglary	Residential and commercial buildings theft, car or vehicle theft, bank theft etc., pickpocketing and usurpation
Sexual Abuse	Rape, Sexual harassment, abuse, molestation etc.
Prostitution	Encouraging prostitution, Mediating prostitution etc.
Fraud	Document and money forgery etc., fraud and fabricate unreal crime.
Assault	Consciously injure and unconscious injure, apply assault
Drug	Buying or selling drug with purpose of use, stimulant drug trade
Irregularity against government	Insulting the government officer and law enforcement officer, damage to public property
Duty and trust abuse	Abuse mission and trust, do not do obligations
Threat	Threat and blackmail
Unexplained events	Accidents, suspicious deaths, suicide, lost property, missing person, intoxication, natural disaster etc.
Industrial accidents	Job accident and job accident death
Traffic accidents	Traffic accident and making dangerous things for traffic security
Irregularity against security and society	Making general security dangerous, crimes against people
Irregularity against person and property	Insult to people, violation of private life, irregularity to person property

Recorded crime data was in Excel format and most of crime dataset did not include coordinate of crimes (they include street information). Crime dataset was containing street information. This problem was solved with linking geocodes of street information in GIS environment. Prior to the geocoding of crime data, errors in street names were corrected and if there were duplicated records in the data, these data were deleted. The collected data were sorted, standardized, and geocoded. Geocoding "hit-rate" was in excess of 98 percent and accuracy of this geocoding for all crime data is sufficient qualitatively to fulfill the research purpose. The obtained data were converted to Transverse Mercator projection system, WGS 84 datum, central meridian 39 coordinate system and all data were made ready for analysis by integrating the geodatabase to be used in ArcGIS 10.8 software.

The geocoded dataset of registered crimes contains 20 005 records between 2011 and 2015. According to geocoded crimes, assault crimes are the most intensive type of crime in all types of crime and other types of crime are unexplained events, burglary, irregularity against person and property, threat. The count of crimes by types and years is given in Table 2. Among five years, 2014 has the most criminal events. The crimes that are divided into 14 main categories according to the purpose and types of crime were mapped out in Figure 2. In addition, symbolic representation of crime types shows places where crimes occurred in January 2014 in Ortahisar, Trabzon. According to crime events,

1) Assault crimes are the most intensive types of offences, with a percentage of 38 of the total number of offences.
2) Unexplained events are the second highest density crime types with 12% percentage of the total all crime events.
3) Burglary crimes are the third highest-density type of crime, accounting for 11% of total crimes.
4) Remaining crime types are irregularity against person and property are with 11%, threat with 7%, irregularity against security with 6%, fraud, drugs and irregularity against government with 3%, sexual abuse, traffic accident are with 2%, industrial accidents, duty and trust abuse, prostitute are with 1%.

Table 2: *Count of crimes by types and year*

Crime Types	Years					Total
	2015	2014	2013	2012	2011	
	Count	Count	Count	Count	Count	Count
Assault	1401	1607	1512	1558	1475	7553
Unexplained events	501	532	431	444	493	2401
Burglary	491	645	373	342	387	2238
Irregularity against person and property	444	592	372	435	337	2180
Threat	393	354	244	177	153	1321
Irregularity against security and society	183	196	261	226	245	1111
Fraud	177	144	111	104	142	678
Drug	123	103	108	124	108	566
Irregularity against government	120	120	114	81	120	555
Sexual abuse	66	91	74	77	70	378
Traffic accidents	183	71	19	24	26	323
Industrial accidents	89	51	33	43	65	281
Duty and trust abuse	89	49	40	34	33	245
Prostitution	31	58	38	48	29	204
Total	**4291**	**4613**	**3730**	**3717**	**3683**	**20034**

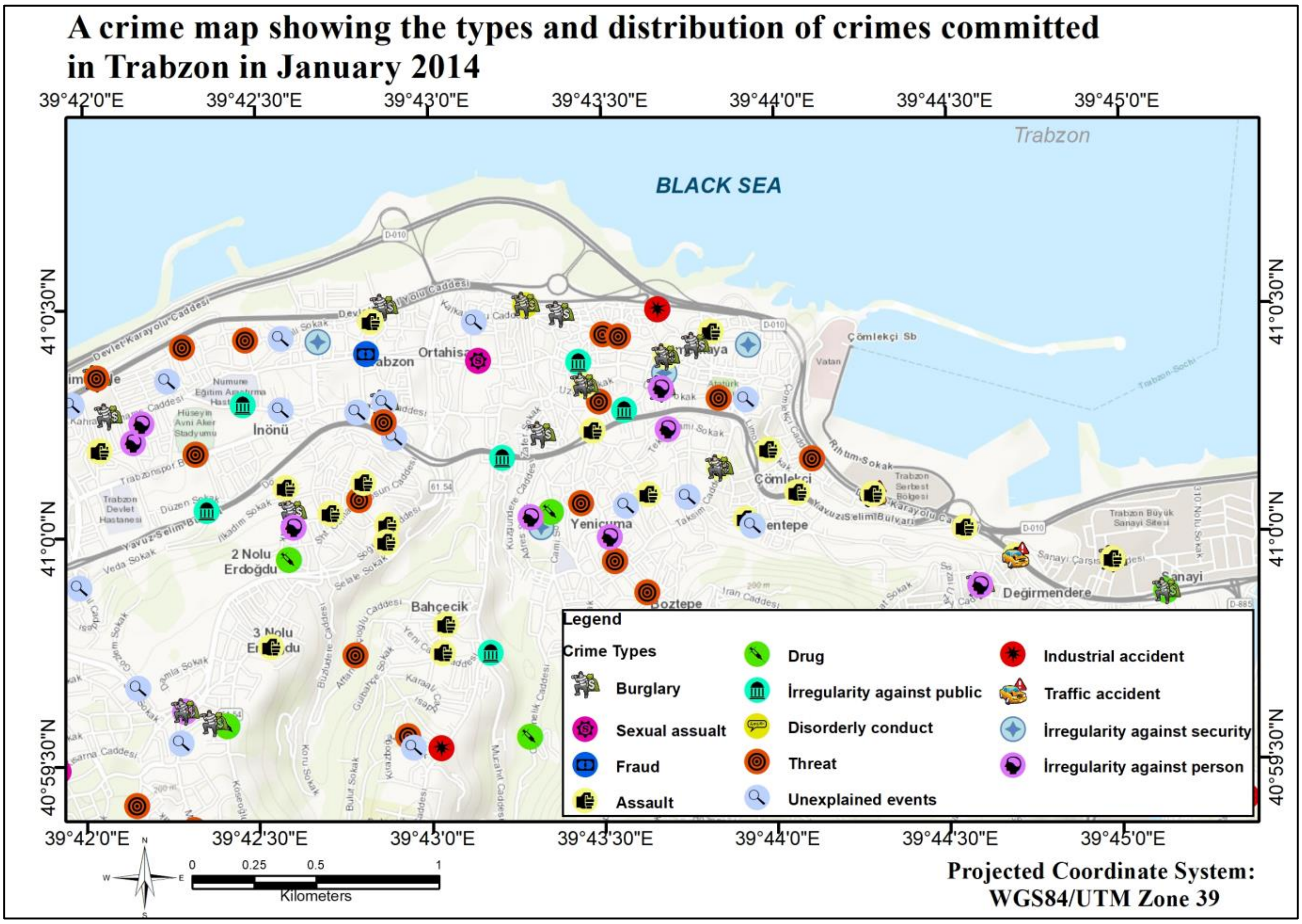

Figure 2: *Symbolic representation of crime types on January, 2014*

3. Results and Discussions

3.1 Spatial Distribution Mapping of All Crime

In this section, spatial crime analysis was applied, and result map are presented in Figure 3. The KDE analysis method was used to determine and map the spatial distribution analysis of all crime events. KDE analysis yields efficient results and the crime mapping presentation obtained as a result of the analysis facilitates the understanding of complex spatial events.

In this context, the KDE analysis of all crimes between 2011 and 2015 was calculated. In KDE analysis, radius value was determined as 200 meters. In the KDE method, a radius is determined for each point and a circular area is drawn around this point. Since density is determined by the number of points inside these circles, it is very important to determine the radius correctly. The distances between crime points were statistically analyzed in ArcGIS software. As the result of the analysis, the expected average distance between crime points was determined as 200 meters. For this reason, 200 meters was selected as the radius for KDE analysis. In the KDE analysis, the grid cell size was chosen as 20×20 meters in accordance with the size of the study area and the data. This map helps us identify where the crime events are of higher or lower density, after calculating Kernel's interpolations. This thematic presentation allows us for interactive visual analysis of crime density and intuitive criminology research.

The crime density zones are visible as cluster on the map. According to Figure 3, the nearest zone of Kemerkaya neighborhood has the highest crime rate. This zone is city center of Trabzon, visited by many people during the day, closes to the main transport lines and has many commercial buildings. The second neighborhood with a high crime rate that follows this neighborhood is the Cömlekci neighborhood. Figure 3 also shows that the lowest crime rate zones are Besirli No. 1, Kanuni and Bostancı No. 1 neighborhoods in the city.

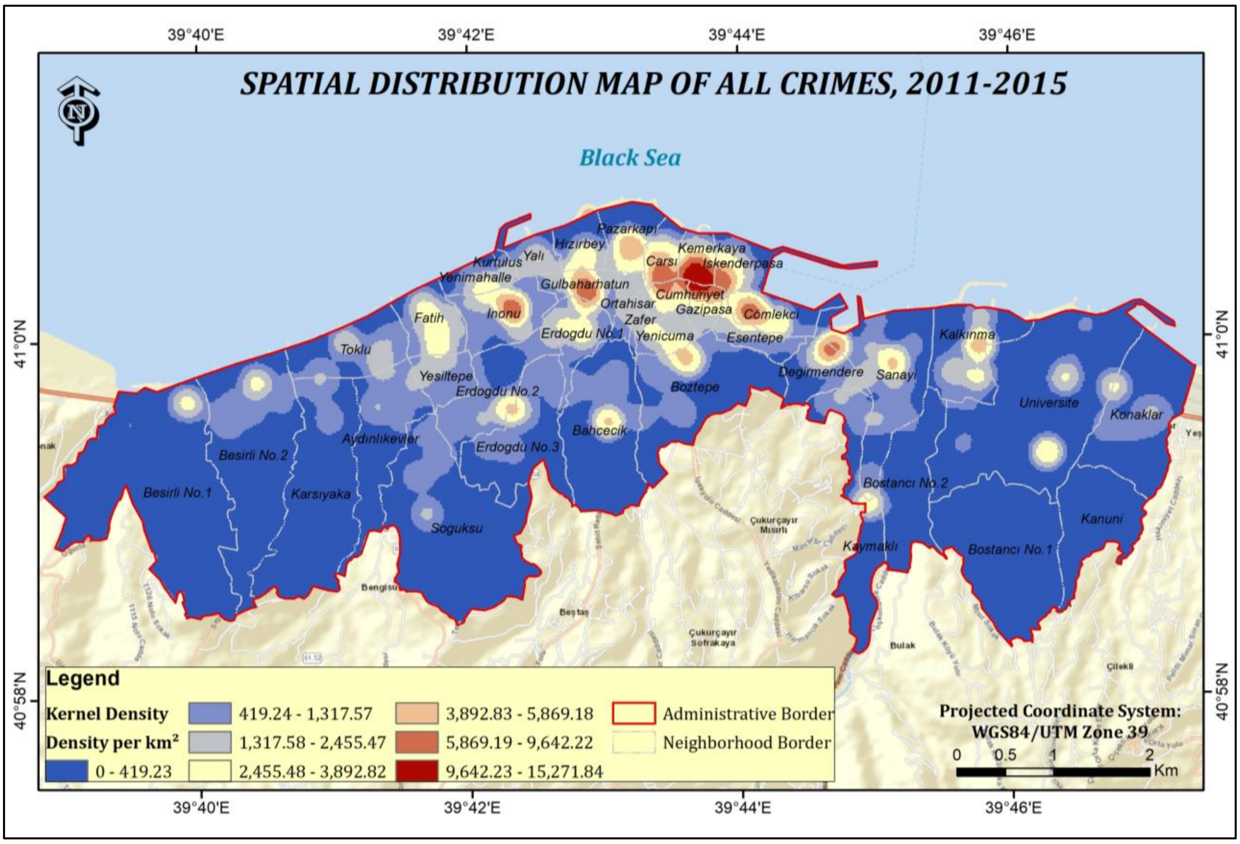

Figure 3: *Spatial distribution map of all crime, 2011-2015*

Figure 4 shows the temporal distributions of crimes by seasonally are shown for important four crime types. When the highest crime rate is investigated seasonally, drug and sexual abuse crime rates are the highest in winter, burglary crime rate is highest in spring and assault crime rate is highest in summer. Depending on the type of crime, the seasons of high crime rates have changed. It should be noted that the total number of assault crimes is almost constant for entire study area in all seasons.

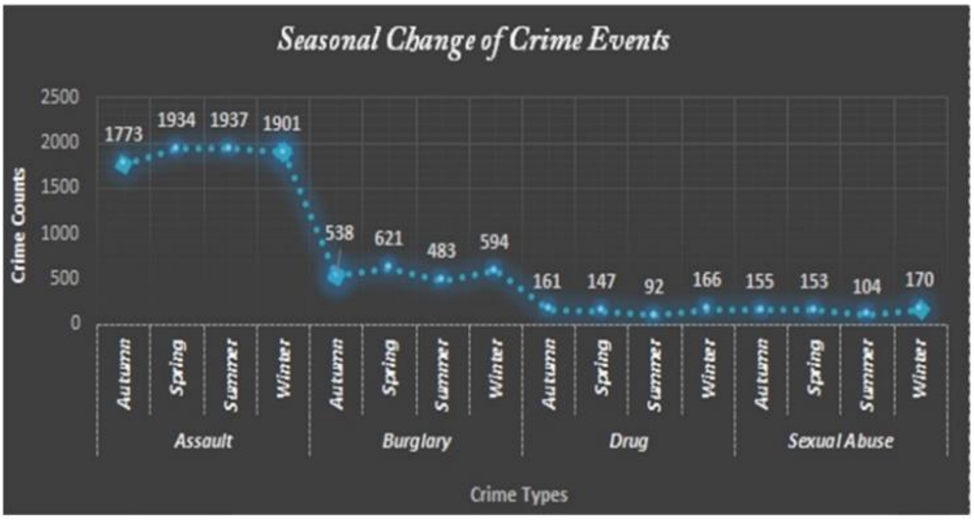

Figure 4: *Seasonal change of crime counts for assault, burglary, drug, and sexual abuse*

3.2 Cartography of Crime – Hexagon Grid Mapping of Crime Density

Cartographical representation and density mapping techniques enable quick understanding of cluster patterns. Hexagon grid mapping technique was used for visualization of spatial and temporal trends of criminal activity. In this study, burglary and assault crimes were selected for analyses because these two types of crime are the most intense in the area of study. Before starting the density analysis, aggregated crime counts by space and time. The assault and burglary crime were summarized by aggregating points in space-time bins. Three months were chosen for the time step interval. One month, two months, three months, and four months were tried as time interval. For each of these four time intervals, it was checked how many hexagon grid locations. The space-time cube aggregated in 2225 points. As a result, 3 months was chosen by examining which time interval gave more statistically significant results over time. 150 meters were chosen for distance interval. 100 meters, 150 meters and 200 meters were tried as distance interval. For each of these three distance intervals, it was checked how many hexagon grid locations. The space-time cube aggregated in 2225 points. As a result, 150 meters was chosen by examining which distance interval gave more statistically significant results.

Space-time cube by aggregating points was created on hexagon grid format. Hexagon format (the polygon bin) was selected because they are preferred in the analysis that includes aspects of connectivity or movement paths (Pobuda, 2018). These parameters affect the number of bins and the size of each bin. These aggregate points were used for analysis where statistically significant clusters of assault and burglary crime are occurred, that are called hotspot analysis. The maps are presented in Figure 5 (a) and burglary crime in Figure 5 (b). For visualization of the two group crimes, the value of the neighborhood time step was set to twenty-time step interval by default and spatial neighbors was set to each bin have at least 50 neighbors.

As a result of burglary crime, the space-time cube has aggregated 2225 points into 2150 hexagon grid locations. Of the 2150 total locations, 420 of them (19.50%) contain at least one point for at least one-time step interval. These 420 locations comprise 8400 space-time bins of which 1537 of them (18.30%) have point counts greater than zero. There is a statistically significant increase in point counts over time.

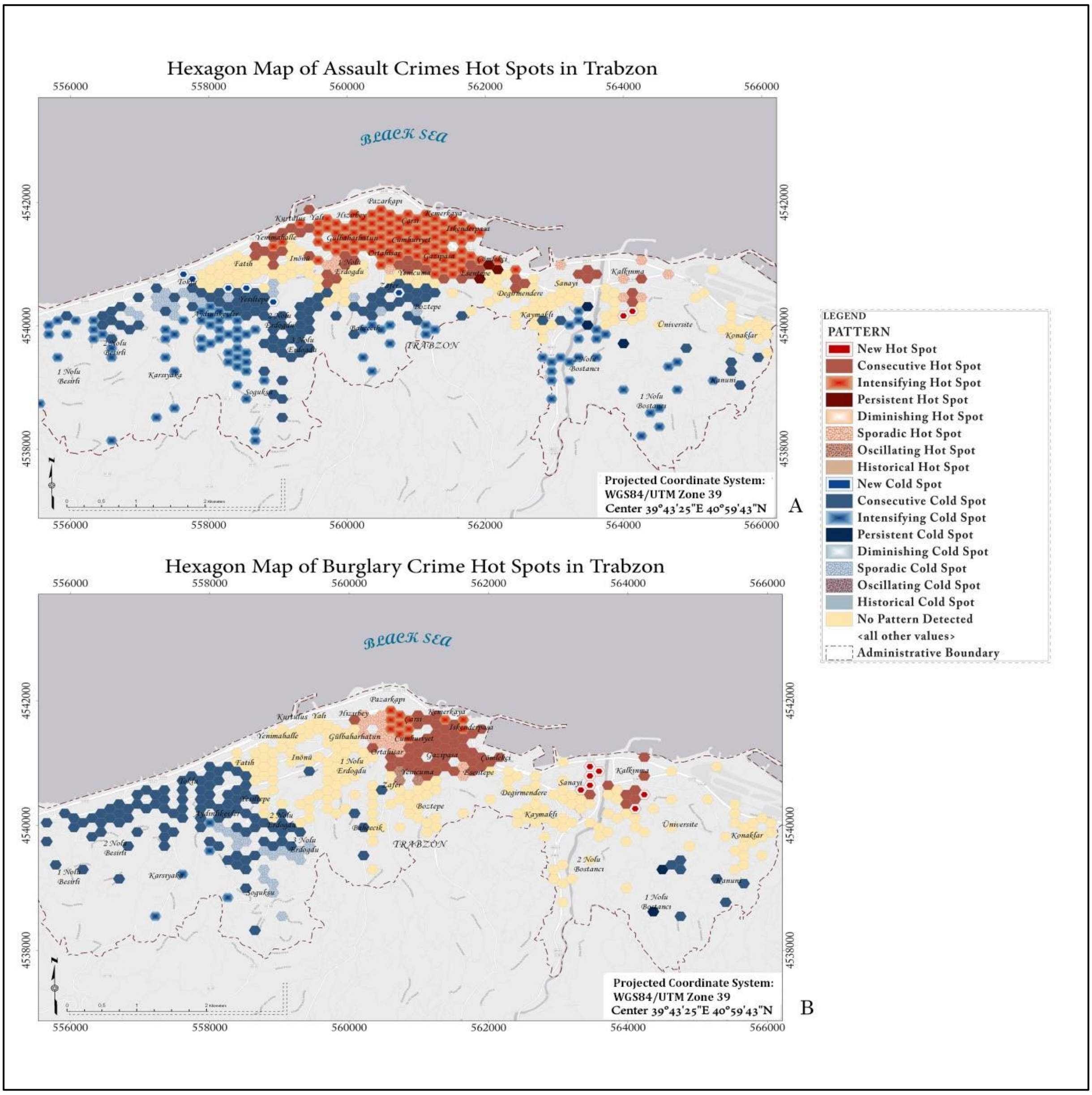

Figure 5: *(a) Hexagon map of burglary crime hotspots in Trabzon between 2011 and 2015 (b) Hexagon map of assault crime hotspots in Trabzon between 2011 and 2015*

On the other hand, for assault crime the space-time cube has aggregated 7499 points into 1850 hexagon grid locations. Of the 1850 total locations, 457 of them (24.70%) contain at least one point for at least one-time step interval. These 457 locations comprise 9140 space-time bins of which 1537 of them (34.69%) have point counts greater than zero. There is not a statistically significant increase or decrease in point counts over time.

These maps were created on a scale of 1/50 000. These maps show statistically significant hot and cold spots. Red areas suggest that there has been clustering of high numbers of crime, and blue areas indicate that over time there has been clustering of low numbers of crime. Each location is categorized based on the trends in clustering over time. As a result of hotspot analysis, 229 of 420 locations are determined hot or cold spot trends for burglary crime while 369 of 489 locations are determined hot or cold spot trends for assault crime.

The locations of the dark red, which are called persistent hotspot; light red with beige outline, that are called intensifying hotspots. The locations of dark red bins do not show a significant increase or decrease in the intensity of clustering of burglary and assault crime counts over time. However, the locations of light red bins where the intensity of clustering of these crime counts is increasing over time. This increase is statistically significant and this significant increase in crime counts includes more areas for assault than burglary crime.

The locations of the dark blue, which are called persistent coldspots; light blue with beige outline, that are called intensifying coldspots. The locations of dark blue bins are areas where crime is statistically and persistently less widespread. However, clusters of low crime counts in light blue outlined bins are becoming more intense over time (the coldspots are getting colder) for assault and burglary crime.

4. Conclusion

Cartographic representation of crime phenomena in spatio-temporal principles is important and necessary for criminal studies. This kind of presenting facilitates the understanding of complex space events and relationships between space and events. The main condition for producing a good crime map is the selection of suitable spatial analyses for crime data and the comprehensibility of cartographic representations. Crime analysis and maps help police authorities to develop predictive policing strategies and decrease crime rates.

In this study, a spatial database model was designed to criminal events. The intensity distribution of all crimes was analyzed and mapped using the KDE method in GIS environment. In addition, hotspots of burglary and assault crime that have the highest crime events were presented to identify crime patterns and were shown on the maps. Hexagon grid mapping technique was used for identification of hotspots of these crimes and statistical result outputs were explained. According to the density distribution map result, while the highest crime rate zones are Kemerkaya neighborhood and Comlekci neighborhood, the lowest crime rate zones are Besirli No. 1, Kanuni and Bostancı No.1 neighborhoods in the city. When the seasonal distribution of crime rates is examined, it has been observed that the seasons with high crime rates change depending on the type of crimes. When the hexagon grid maps were examined, there is a statistically significant increase in point counts of burglary crime over time. However, there is not a statistically significant increase or decrease in event counts of assault over time.

One of the main purposes of the paper is the creation of maps and other outputs helping perception of decision makers and people for investigating and understanding crime. More overly, this study is not only a visualization study, but also a study for enhancing the ways to refine the results of GIS-based crime analysis. It is a real-life problem that people or experts sometimes cannot see relations and occurrence reasons of crime events. In this respect, the study offers a good understanding. On the other hand, hexagonal mapping methods bring ways that are more aesthetic for representing crime events. Spatio-temporal crime data can be easily analyzed and represented via GIS-based systems. However, incorporating different advanced analyses and visualization tools into the study may be beneficial for future studies.

While crime data analysis processes may be easier due to the availability of crime databases in developed countries, it is not easy to collect crime data due to the lack of ready-to-use and standardized crime databases in Türkiye. This situation restricts the GIS-based spatial crime studies. Crime data sharing should be facilitated in order to increase and develop studies in this field in Türkiye.

The 3D visualization of crime events also supports understanding of crime distributions and is very useful for third party people. Cartographic techniques used in this study enable a more effective understanding of spatial and temporal distribution of crimes. These techniques can be used productively for the representation of crime events.

Software

The original crime data was received in MS Excel format. Spatial and non-spatial data was collected and maintained in ESRI ArcGIS geodatabase. The mapping and analysis of all crimes were applied using ArcMap 10.4.1. Mapping of hotspots for burglary and assault crimes based on hexagon mapping techniques was applied using ArcGIS Pro. Finally, Adobe Photoshop CC 2018 was used to design the final status of maps and figures.

Author Contribution

Gamze Bediroglu: Conception, Design, Literature review, Data collection, Analysis and interpretation, Writing. **Ebru Colak:** Literature review, Supervision, Review of article.

Declaration of Competing Interests

The authors declare that they have no known relevant competing financial or non-financial interests that could have appeared to influence the work reported in this paper.

References

Aliagaoglu, A., & Cildam, S. Y. (2016). Bandırma Şehrinde Suçlar (2006-2008): Coğrafi Bir Yaklaşım. *Balıkesir Üniversitesi Sosyal Bilimler Enstitüsü Dergisi*, *19*(35).

Beiji, Z., Mohammed, N., Chengzhang, Z., & Rongchang, Z. (2017). Crime hotspot detection and monitoring using video based event modeling and mapping techniques. *International Journal of Computational Intelligence Systems*, *10*(1), 962.

Boba, R. L. (2005). *Crime Analysis and Crime Mapping*. Thousand Oaks, California, Sage Publications.

Chainey, S., & Ratcliffe, J. (2005). *GIS and Crime Mapping*. Chichester, John Wiley & Sons Inc.

Chainey, S., Tompson, L., & Uhlig, S. (2008). The utility of hotspot mapping for predicting spatial patterns of crime. *Security Journal*, *21*(1), 4–28.

Eck, J., Chainey, S., Cameron, J., Leitner, M., & Wilson, R. (2005). *Mapping Crime: Understanding Hot spots*. Washington, DC: U.S. Department of Justice, National Institute of Justice.

Eken, S., & Kumru, P. (2014). Haritalar Üzerinde Suç Verilerinin Görüntülenmesi ve Analizinin Sağlanması: Kocaeli İli Örneği. *KMÜ Sosyal ve Ekonomik Araştırmalar Dergisi*, *16*(1), 67-72.

Ejemeyovwi, D. O. (2015). Crime mapping using time series analysis in Asaba, Delta State, Nigeria: a remote sensing and GIS approach. *European Journal of Basic and Applied Sciences*, *2*(2), 52-71, ISSN: 2059-3058.

Feng, J., Dong, P., & Song, Y. (2016). A Spatio-Temporal Analysis of Urban Crime in Beijing: Based on Data for Property Crime. *Urban Studies*, *53*(15), 3223-3245.

Gahlin, C., & Johansson, E. (2014). Crime Hotspots: An Evaluation of the KDE Spatial Mapping Technique (Thesis). Blekinge Institute of Technology, Faculty of Computing, Department of Computer Sciemce & Engineering, Karlskrona, Sweden.

Gayır, B., & Arslan, O. (2018). Orman Yangınlarının CBS Tabanlı Konumsal İstatistik Analizi: 2011-2015 Yılları Arasında Muğla Orman Bölge Sınırları İçerisinde Çıkan Yangınlar. *Anadolu Orman Araştırmaları Dergisi*, *4*(1): 44-60.

Gerber, M. S. (2014). Predicting crime using Twitter and kernel density estimation. *Decision Support Systems*, *61*, 115-125.

Glasner, P., & Leitner, M. (2017). Evaluating the Impact the Weekday Has on Near-Repeat Victimization: A Spatio-Temporal Analysis of Street Robberies in the City of Vienna, Austria. *ISPRS International Journal of Geo-Information*, *6*(3).

Gupta, R. Rajitha, K., Basu, S., & Mittal, S. K. (2012). Application of GIS in Crime Analysis: A Gateway to Safe City. *Proceedings of the 14th Annual International Conference and Exhibition on Geospatial Information Technology and Applications*, India.

Gurbuz, M., & Karabulut, M. (2007). Adana Beş Ocak Polis Karakolu Sorumluluk Bölgesinde Çocuk Suçlarının Coğrafi Bilgi Sistemleri ile Haritalandırılması ve Analizi. *Çukurova Üniversitesi Sosyal Bilimler Dergisi*, *16*(1), 331-346.

Gurbuz, M., Karabulut, M., & Temir, Ö. (2013). Kayseri'de Oto ve Otodan Hırsızlık Suçlarının CBS ile Haritalandırılması ve Analizi. *KSÜ Sosyal Bilimler Dergisi*, *10*(1).

Gwinn, S. L., Bruce, C., Cooper J. P., & Hick, S. (2008). *Exploring Crime Analysis: Readings on Essential Skills (2nd ed)*. Overland Park, KS: International Association of Crime Analysts.

Hajela, G., Chawla, M., & Rasool, A. (2021). Crime hotspot prediction based on dynamic spatial analysis. *Electronics and Telecommunications Research Institute (ETRI), 43*(6), 1058-1080.

Hart, T. C., & Zandbergen, P. A. (2014). Kernel density estimation and hotspot mapping: Examining the influence of interpolation method, grid cell size, and bandwidth on crime forecasting, *Policing An International Journal of Police Strategies and Management, 37*(2).

Hirschfield, A., & Bowers, K. (2001). *Mapping and analysing crime data*. London and New York, Taylor & Francis.

Hu, Y., Miller, H. J., & Li, X. (2014). Detecting and analyzing mobility hotspots using surface networks. *Transactions in GIS*, *18*(6), 911–935.

Hu, Y., Wang, F., Guinc, C., & Zhub, H. (2018). A spatio-temporal kernel density estimation framework for predictive crime hotspot mapping and evaluation. *Applied Geography, 99*, 89–97.

International Association of Crime Analysts (IACA) Standards, Methods, & Technology (SMT) Committee. (2013). Identifying High Crime Areas (White Paper 2013-02), Overland Park, KS: Author.

Kalinic, M., & Krisp, J. M. (2018). Kernel Density Estimation (KDE) vs. Hot-Spot Analysis - Detecting Criminal Hot Spots in the City of San Francisco. *Proceedings of the 21st Conference on Geo-information Science*, Lund, Sweden.

Kumar, G. R. P., & Somashekar, R. K. (2012). GIS Based Crime Mapping and Analysis: A Case Study of Mudugiri Town Police Station Jurisdiction, Tumkur District, Karnataka, India. *GIS crime mapping and analysis, 1*(1).

McCullagh, M. J. (2006). *Detecting Hot spots in Time and Space*. ISG06.de Smith MJ.

Mohler, G. (2014). Marked point process hot spot maps for homicide and gun crime prediction in Chicago. *International Journal of Forecasting, 30*, 491-497.

Paynich, R., & Hill, B. (2010). *Fundamentals of Crime Mapping*. Sudbury, MA: Jones and Barlett.

Pobuda, M. (2018). *Analyze Crime Using Statistics and the R-ArcGIS Bridge*. https://learn.arcgis.com/en/projects/analyze-crime-using-statistics-and-the-r-arcgis-bridge/lessons/install-the-r-arcgis-bridge-and-start-statistical-analysis.htm (Accessed: 25 October 2021).

Ratcliffe, J. H. (2004). The hotspot matrix: A framework for the spatio-temporal targeting of crime reduction. *Police practice and research*, *5*(1), 5-23.

Turkish Statistical Institute (TUİK) (2021). Statistics Data Portal.

Wang, X., Gerber, M. S., & Brown, D. E. (2012). Automatic crime prediction using events extracted from twitter posts. In *International conference on social computing, behavioral-cultural modeling, and prediction* (pp. 231-238). Berlin, Heidelberg: Springer Berlin Heidelberg.

Wolff, M., & Asche, H. (2019). A 3D Geovisualization Approach to Crime Mapping. *Proceedings of the 24th International Cartographic Conference*, Santiago, Chile.