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SPATIAL AND TEMPORAL ANALYSIS OF URBAN CRIME FACTORS IN KAUNAS CITY, LITHUANIA

Abstract: Crime is a negative phenomenon that can highly influence the economic and social state of an area and is relevant to every country in the world. Crimes are recognized to be one of the main factors that disrupt a healthy society, as it can cause a disruption of its state, by leaving the limitations of insecurity, anxiety, and mental distress among the citizens. This article aims to investigate spatio-temporal dimensions which affect the urban crime level in the city of Kaunas. The research question – to what extent do population density, age and unemployment rate affect the Urban Crime in the city of Kaunas, Lithuania (2008–2021)? The mapping of crime prevalence has demonstrated that population density in different parts of the city has a direct correlation with the amount of crime. However, this relationship weakens as one moves away from the central parts of the city. Also, crimes are the most prominent in the middle of the city of Kaunas and become rarer when moving out. The relationship between mean age of population and crime prevalence showed a bell-shaped curve, and therefore the hypothesis that there is an association between age structure of population and crime prevalence is partially supported. However, due to lack of data, the relationship between the age structure of the population and the crime prevalence in that area could not be found statistically reliable.

Key words: Spatio-temporal analysis, Urban crime, Kaunas, factors

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INTRODUCTION

Crime is a negative phenomenon that can highly influence the economic and social state of an area and is relevant to every country in the world. It can be described as "the intentional commission of an act usually deemed socially harmful or dangerous and specifically defined, prohibited, and punishable under criminal law" (Edge, Bernard 2018). Crime is indeed a significant factor that can disrupt a healthy society, leading to feelings of insecurity, anxiety, and mental distress among its citizens. It is crucial to address these issues to maintain a safe and stable community for everyone (Kassem et al. 2019). This article aims to investigate spatio-temporal dimensions (population density, age and unemployment rate in 2008–2021) which affect the urban crime level in the city of Kaunas. The question is worth asking, since studying the factors influencing the crime levels on the neighbourhood level, can help to implement knowledge-based solutions which prevent or minimize the criminal acts from occurring, so enhancing the level of safety and security of an area and improving the quality of living of the citizens.

In terms of geographical context, Kaunas is the city located in the centre of Lithuania, a country in the centre of Europe (Figure 2). It is the second largest city with approximately 301,300 citizens[1]. During the year 2021, 1701.8 crime acts were recorded for 100,000 citizens in Kaunas[2], compared to the 2276,1 crime acts for 100,000 citizens in Gdansk (Poland), or 1668,9 crime acts for 100,000 citizens in Lublin city, Poland[3]. This shows that Kaunas had a generally similar crime rate to the most cities in Poland. City of Kaunas is divided into 11 districts in total, which are presented in the map bellow and will be used when describing and identifying patterns of crime throughout the study. The empirical analysis is done on a level of 500 m × 500 m grid.

The crime rate can be defined as a relative number of crimes to the size of population and is usually expressed as the number of crimes per 100,000 citizens in the population[4]. As the crime rate is a relativized number, it allows to make comparisons. It is important not to mix up this term with the definition of crime prevalence (crime volume), which just defines the total number of acts of crime committed in the particular area (Battin, Crowl 2017). In this study, crime prevalence will be used for testing the relation between crime and a particular factor – population density, mean age (unemployment rate).

Studies on urban crime in an area state that it can be influenced by a variety of different factors, but it is important to understand that it is difficult to measure their influence separately, since in real life they always work together. Previous research has shown that there is a strong correlation between crime and the urban environment, which allows the crime to be explored and analysed at different geographic levels (Wortley, Mazerolle 2008; De Nadai et al. 2020). The factors affecting the crime level can include demographic, social and economic factors like variations in composition of the population, poverty level, unemployment rate, median income, education level and others[5]. For this study, the influence of demographic factors including population density and composition of population, and the effect of a social-economic factor: unemployment rate, was selected to be tested on how it correlates with the level of crime.

Population density can be referred to as being the number of people per unit of area. While some scientists believe that higher population density increases the number of crimes committed, due to there being more individuals likely to commit a crime, others argue that more people living in an

[1] https://osp.stat.gov.lt (accessed: 25.08.2023).

[2] https://ird.lt/lt/atviri-duomenys-2 (accessed: 28.08.2023).

[3] https://cbsp.policja.pl (accessed: 15.04.2024).

[4] https://dictionary.cambridge.org/dictionary/english/crime-rate (accessed: 12.07.2023).

[5] https://ucr.fbi.gov/ (accessed: 8.09.2023).

area would mean there are more witnesses, which makes it harder to carry out a criminal act. Additionally, the presence of more potential victims in densely populated urban areas may also attract criminals, leading to a higher incidence of certain types of crimes. "The relationship of population density and crime is a difficult one to predict because of the differing effects of population density on the probability of apprehension and supply of criminal opportunities" (Hovel 2014, p. 8). It is also worth mentioning that the results of previous studies performed on testing the correlation between these two factors have been contradictory. For example, a positive correlation between the population density and crime levels has been found in the studies performed in Punjab, Pakistan (Kassem et al. 2019), and in the United States (Harries 2006). However, a significant and negative correlation between these variables was found during a study performed in the cities of Cleveland and San Diego, USA (Roncek 1981).

Also Mean age factor was selected. It is important to note that the researchers analyse two aspects related to Mean Age and territory. The first is how societies' mean age determines the crime rate, and the second is how the mean age of population in an area can determine the crime rate in that area. During different scientists' previous studies, the Age-Crime Curve (ACC) was used and analysed, which describes the relationship between crime and age, and is one of the greatest theories in criminology due to its consistent findings. The ACC demonstrates an asymmetrical bell shape which suggests that the likelihood of committing crime increases faster through adolescence and gradually slower decreases with adulthood (Matthews, Minton 2017). Therefore, the populations with a higher proportion of youth are expected to have higher crime rates. Although the correspondence of age on crime is clearly understood, the various factors that could influence the changes in ACC are under investigation (Flores De Apodaca et al. 2015). The conflict thus arises whether the ACC is universally invariant or does it differ over time, between countries, and between men and women (Matthews, Minton 2017).

The second approach – the age structure of the society in a territory has the biggest influence on the crime level in that place (Schneider 2002). Additionally, the reason why the crime rates differ with area mean age is not yet determined and varies greatly (Sweeten et al. 2013). Based on the studies mentioned above, it is important to analyse how the age of the population of a selected city determines the crime rate. However, there is a margin of error, as offences can be committed by people coming from another location.

Unemployment rate defines the percentage of unemployed individuals in an economy among individuals currently in the labour force. Persons in unemployment are defined as all those of working age who are not in employment, carried out activities to seek employment during a specified recent period and are currently available to take up employment given a job opportunity[6]. It is thought that the unsteady economy results in higher crime rates. Unemployment rates is one of the factors that can often reflect the health of the economy (Ajimotokin et al. 2015). Economic crises can lead to lower unemployment rates caused by reduced demand for labour, and since the standard of living falls and many loose the disposable income, more people are willing to commit crimes (Ajimotokin et al. 2015; Schleimer et al. 2022). Distribution of businesses can also lead to an increase in crime, as they are like attractors for certain types of crime (e.g. theft) (Ajimotokin et al. 2015; Battin, Crowl 2017). Where there are not many businesses, unemployment can be higher (Jonathan et al. 2021).

The study developed testable hypotheses, which were linked to mentioned factors from the analysis of scientific papers.

Population density:

H_0: The crime prevalence is independent to the population density in the city of Kaunas.

H_1: The crime prevalence is not independent to the population density in the city of Kaunas.

Age structure of the population:

[6] https://ilo.org/wcmsp5 (accessed: 11.09.2023).

H: The relationship between the mean age and crime prevalence demonstrates a bell-shaped curve in the city of Kaunas.

Unemployment rate:

H_0: The crime rate is independent to the unemployment rate in the city of Kaunas.

H_1: The crime rate is not independent to the unemployment rate in the city of Kaunas.

METHODOLOGY

Data collection methods

This study primarily uses secondary data that was obtained from the Information Technology and Communications Department (IRD), Official Statistics Portal (OSP) and HNIT-Baltic[7]. Dataset of crime acts, recorded throughout the year 2021, was obtained from (IRD) and "Population Census" data of the year 2021, provided by OSP, was used to obtain population density dataset. The datasets collected are in a raster form (grid size 500 × 500) (Fig. 1).

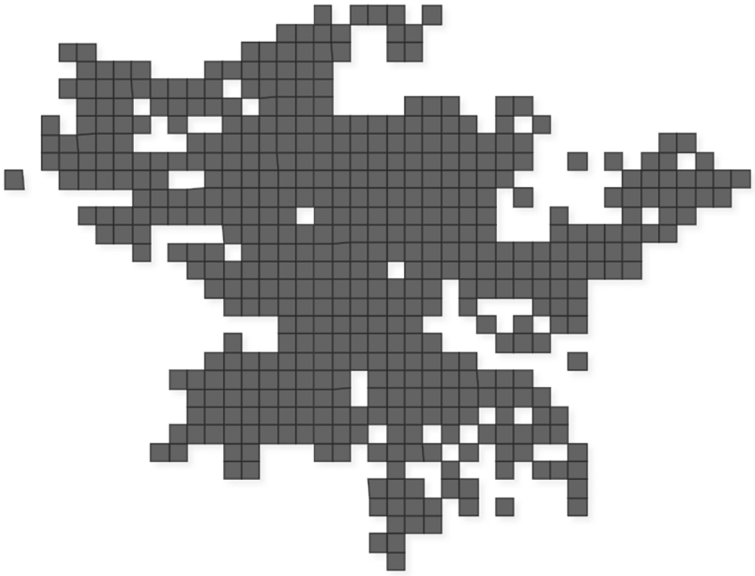

Fig. **1**. A visual example of a raster data set
Source: own elaboration.

For the test of the dependence of crime rate on the unemployment rate, unemployment rate data for the years from 2008 to 2021 was obtained from (OSP), and crime rate data for the same time-period was provided by (IRD).

Specific analysis methods

Demographic factor: Population density. To test the relationship between the population density and the crime prevalence, an online tool, ArcGIS online, was used, where a map from

[7] https://www.gisbaltic.eu/lt-lt/home (accessed: 21.09.2023).

the collected raster datasets was created. Two different datasets were combined using a "Join Features" tool. This allowed to perform a spatial analysis in which the patterns of different variables and their relationship with each other can be discovered and visualized on a map.

Later, a scatter plot graph using the datasets was created and the Spearman's rank correlation coefficient "R", and the coefficient of determination (R^2) were calculated. Due to a large number of data points in the sample, the calculations were performed using the Microsoft Excel software. The values were used to identify the strength and nature of the relationship between the two variables.

$$R = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)}$$

Spearman's rank correlation coefficient formula

As the reliability of the model also depends on the sample size, p-value was calculated to identify if the relationship can be held as significant, and whether the null hypothesis (H_0) can be rejected. T-statistic was firstly estimated using a formula, and then the p-value was calculated using the TDIST (x,deg_freedom,tails) function in Excel[8].

$$t = \frac{R \times \sqrt{n-2}}{\sqrt{1 - R^2}}$$

T-statistic formula for Spearman correlation

Demographic factor: Age structure of the population. Using the Census data of the mean age and the crime prevalence data from IRD in that particular area, a scatter plot diagram was created. From the diagram the relationship between the two variables has been identified and the pattern was described.

Economic-social factor: Unemployment rate. Using the crime rate and the unemployment rate data from the year 2008 to 2021, the dependence of crime rate on the change of unemployment rate will be discovered. Scatter plot diagram will be created and both: Spearman's rank coefficient (R) and coefficient of determination (R2) will be calculated.

The choice of this time period can be justified by the fact that during the year 2008, the Global financial crisis caused Lithuania to experience the greatest negative impact on the state of its economy, and thus, this has resulted in the reduced demand for labour, which means a lower employment (Gutauskas 2011). Using the data from this time period allows us to compare the crime rates to significantly changing rates of unemployment.

DATA PRESENTATION AND ANALYSIS

Firstly, a map containing only the distribution of the total number of crime acts recorded was created (Fig. 2). As seen in the map, criminal acts are the most prominent in the middle and North-East region of the city including the majority of Dainava, Centras and Girčiupis. Some crime spots can be noticed in other districts that include Eiguliai, Šilainiai, Vilijampolė, Šančiai and Žaliakalnis. Additionally, outer city region displays noticeably lower crime rates.

Population density is the first factor that the relationship with crime prevalence was tested on. The map showing the distribution of population density in the city of Kaunas that was created in "ArcGis online" is presented below (Fig. 3).

[8] https://www.exceldemy.com/ (accessed: 21.07.2023).

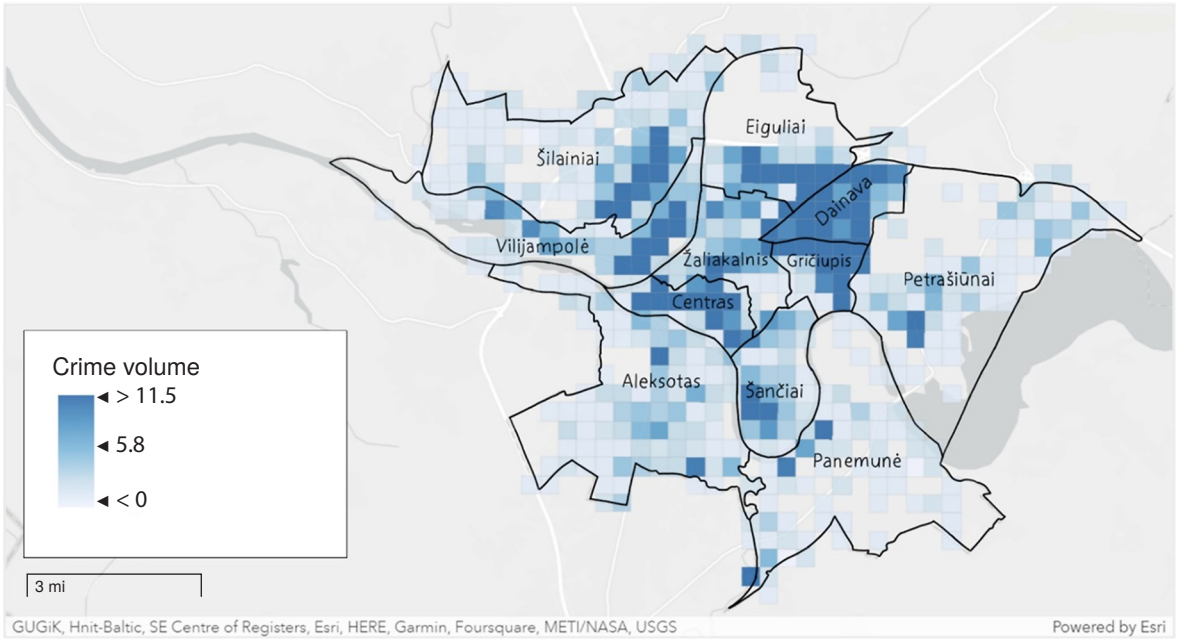

Fig. **2**. A map, made using "ArcGis online", showing the distribution of crime prevalence in Kaunas
Source: own elaboration.

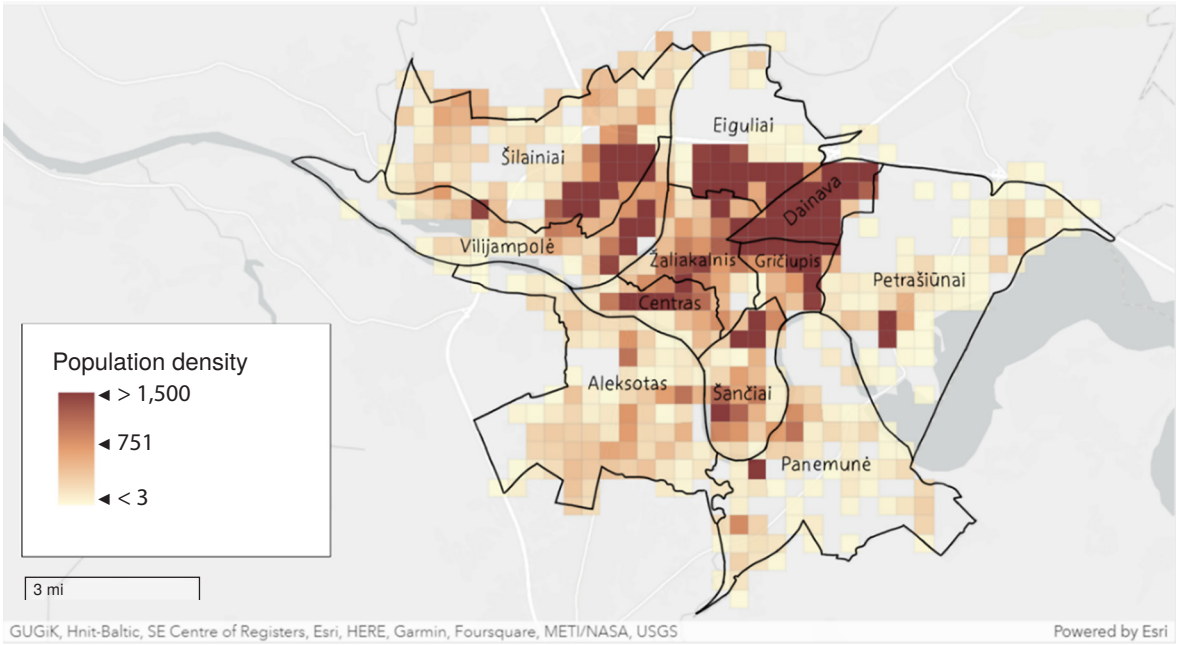

Fig. **3**. A map, made using "ArcGis online", showing the distribution of population density in Kaunas
Source: own elaboration.

From this map, it can be said that there is a great difference between population density in different districts. Districts with the highest population density are located towards the middle and North-East region of the city. Districts include: Centras, Žaliakalnis, Gričiupis, Dainava, Eiguliai, Vilijampolė, Šilainiai and Šančiai, and are expected to have a generally higher crime prevalence. Areas located

more towards the edges of the city or in the South, have a generally lower population density areas, and are expected to have a lower crime prevalence. The map showing the relationship between the number of crimes recorded and the number of people living in the area is presented below (Fig. 4).

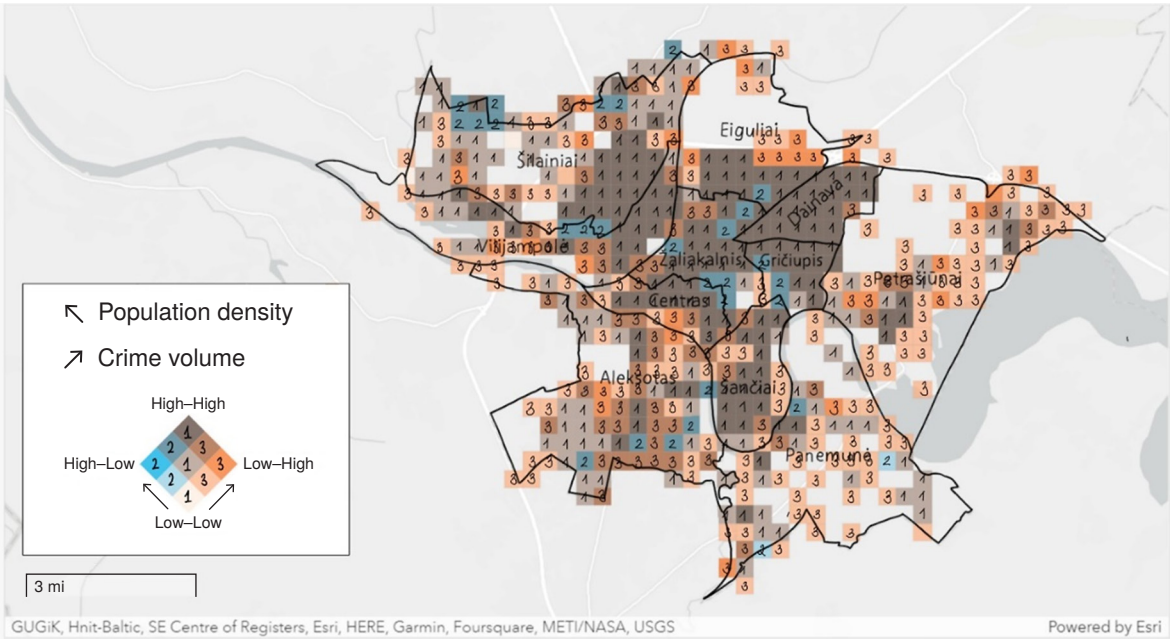

Fig. **4**. A map, made using "ArcGis online", showing the relationship between population density and the crime prevalence
Source: own elaboration.

As shown in the map, throughout the city, the results drastically vary. Large amount of the middle row colours (marked by the number 1 on the map legend) does suggest that the number of crimes does depend on population density at least to some extent. However, a large amount of orange colour present (marked by the number 3 on the map legend) could indicate that in some areas of the city crime rates would be expected to be higher according to the perfect correlation. Only some blue colour is present (marked by the number 2 on the map legend) which means that in those areas crime prevalence is relatively higher for the population density than suggested by the perfect correlation. Even though visual maps are helpful in detecting if there is a correlation present between the two variables, it is not possible to estimate the strength or the significance of the relationship. For this reason, a scatter plot diagram was created (Fig. 5).

From the scatter plot diagram, a positive correlation between the two variables can be noticed, which does indicate that higher population density results in more crime acts committed in that particular area. Spearman's rank correlation coefficient of 0.66 indicates a relationship of a medium strength between the variables. In addition, R^2 value of 0.43 does indicate that 43 per cent of variation in crime prevalence can be explained using the density of population.

The results could be held as highly statistically significant, as the p-value is smaller than 0.01, which does indicate that there is sufficient evidence to reject the H_0 hypothesis and accept the H_1 hypothesis. Therefore, there is an association between the population density and crime prevalence. This has been particularly noticeable in more densely populated areas of Kaunas city.

It is important to mention that such a low p-value could be explained by a large sample size used as "with a very large sample, the standard error becomes extremely small, so that even minuscule distances between the estimate and the null hypothesis become statistically significant" (Lin et al.

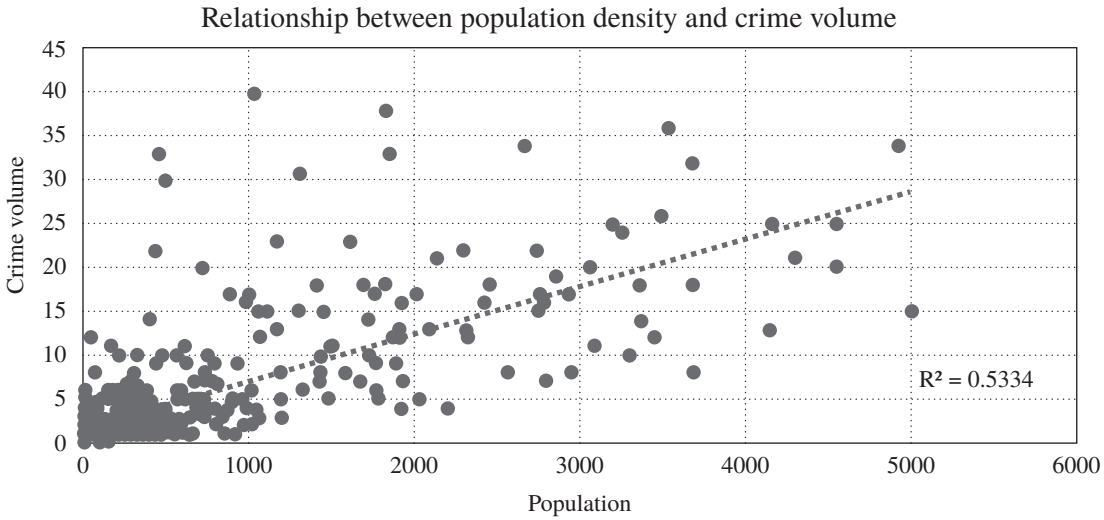

Fig. **5**. Scatter plot diagram showing the correlation between population density and crime prevalence
Source: own elaboration.

2013). Due to this, a high p-value could have led to a false positive or negative relationship, however as the R value is relatively strong, this would not apply.

Although a relatively high R value shows that there is a correlation between the population density and crime prevalence, the variance in the results could be explained by a relatively small geographical region that was chosen to be tested, as then the problem of spatial autocorrelation arises due to the fact that each observation can affect all others that surround it, and thus does not follow the assumption of independence of observations (Hovel 2014).

Another possible reason for the variance in data could be explained by the fact that the Census data only reflects residential population rather than the actual population at risk (residents plus temporary arrivals), which differs because of the daily routine movement between the residential areas and commercial areas in urban environments (Jung et al. 2020). For instance, during the day many would leave the residential areas for work, and the population of risk there would become smaller, while on the contrary, commercial areas would have a way higher population at risk during the work hours for some types of crime. That areas with more people (during the day) offer more opportunities for criminal activities. This could result in areas with a small population density exhibiting high crime prevalence and vice versa. Therefore, the results might be misleading and would not demonstrate the real relationship between the population density and crime prevalence. However, this approach might have only a minimal effect in the city of study, since the areas with the highest population densities are also the ones that demonstrate the characteristics of commercial places. This can be seen in the map provided above, which shows the distribution of businesses in Kaunas (Fig. 6). Clearly, further research into the relationship between the size of businesses, their distribution and the prevalence of crime could reveal additional relationships, but this is a matter for future research.

Age structure of the population. The scatter plot diagram showing the relationship between mean age of population and crime prevalence (crime volume) in the particular area (Kaunas city) is presented below (Fig. 7). It represents what influence has the mean age of the society in a particular territory on the crime prevalence in that place.

From the scatterplot, an asymmetrical bell-shaped distribution can instantly be noticed with the crime prevalence starting to increase from around the mean age of 25 years old, peaking at around

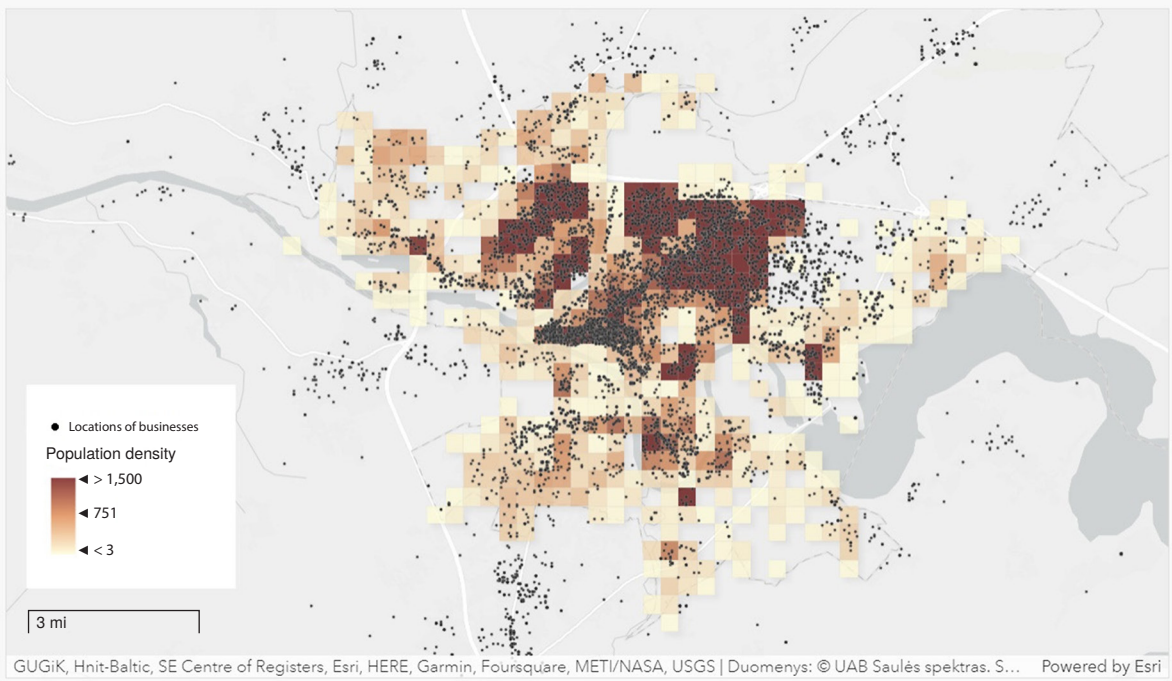

Fig. 6. A map, made using "ArcGis online", showing the distribution of businesses and the population density
Source: own elaboration.

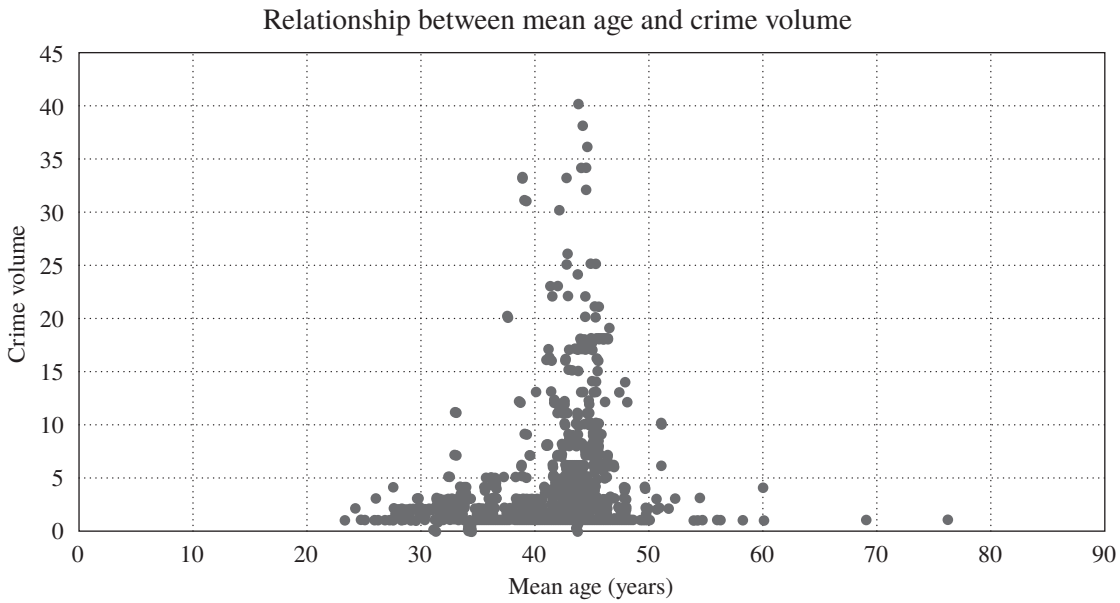

Fig. 7. Scatter plot diagram showing the relationship between mean age of population in area and crime prevalence (2021 data)
Source: own elaboration.

45 years old, and gradually decreasing after. This diagram could suggest that mean age in the area does have an impact on the crime levels. Therefore, the data shows a normal distribution of crime prevalence around the mean age.

Even though the scatterplot diagram demonstrated a relationship between the average age of the population and the crime prevalence following the expected bell-shape distribution, the true correlation between the two variables can be said to be hidden due to using the mean value of age in a particular territory, rather than the proportion of each age group in the area. This is the evidence (Schneider 2002; Sweeten et al. 2013) of the correlation mentioned in the work of other researchers.

Social-economic factor: unemployment rate is the next factor which influence on crime rate will be tested on. The table showing the data collected for unemployment rates and crime rates throughout the years is presented below (Fig. 8).

To have a visual representation of the changing unemployment and crime rate trends throughout the years, a graph using the data from the table was created and is presented below (Fig. 8). Unfortunately, there is no unemployment data that can be represented at the 500 m × 500 m level. Therefore, a limited analysis has been chosen, comparing aggregated data for Kaunas city.

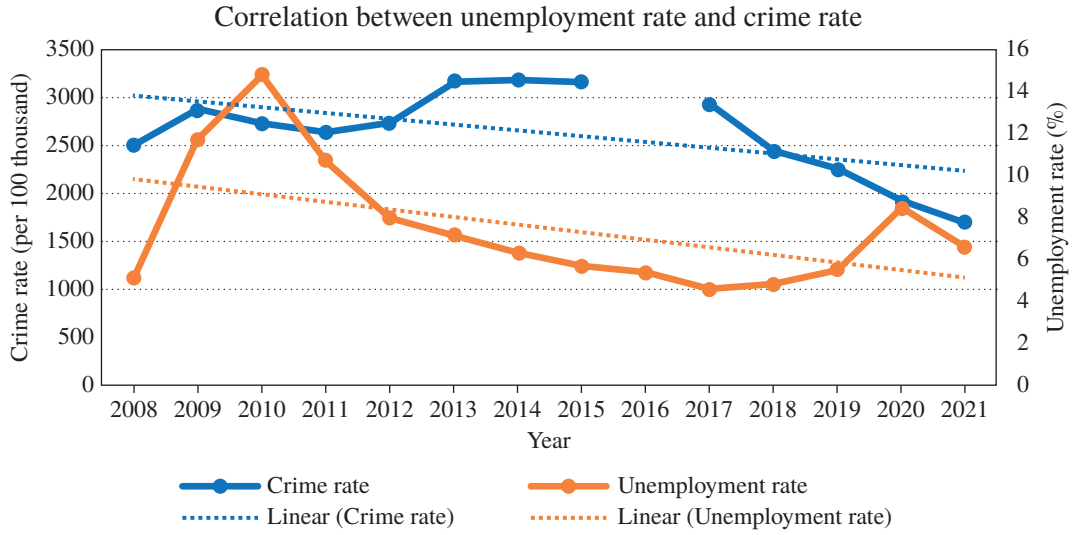

Fig. 8. A graph showing the changing trends of unemployment and crime rates throughout the years[9]
Source: own elaboration.

From the graph, it is clear that the unemployment rate was varying drastically throughout the years. From 2008 to 2010 it experienced a rapid growth, and in year 2010 it reached the highest point during the last 14 years. Since then, it had been constantly decreasing until the year 2019. The unemployment rate can be seen peaking once again during the year 2020.

The crime rate increased during the years 2008 and 2012. It stayed consistent from the year 2009 to 2012 and during the years from 2013 to 2015. However, the crime rates showed a steady decrease throughout the years from 2017.

The crime rate, equivalent to unemployment rate, both showed a general downward trend throughout the years. However, it is hard to distinguish an exact influence of unemployment rates on crime rates using this graph alone, so a scatter plot diagram with a line of best fit was created, and the cor-

[9] It is worth mentioning, that there was no available data for the crime rate recorded in 2016 so that particular data point was set as missing.

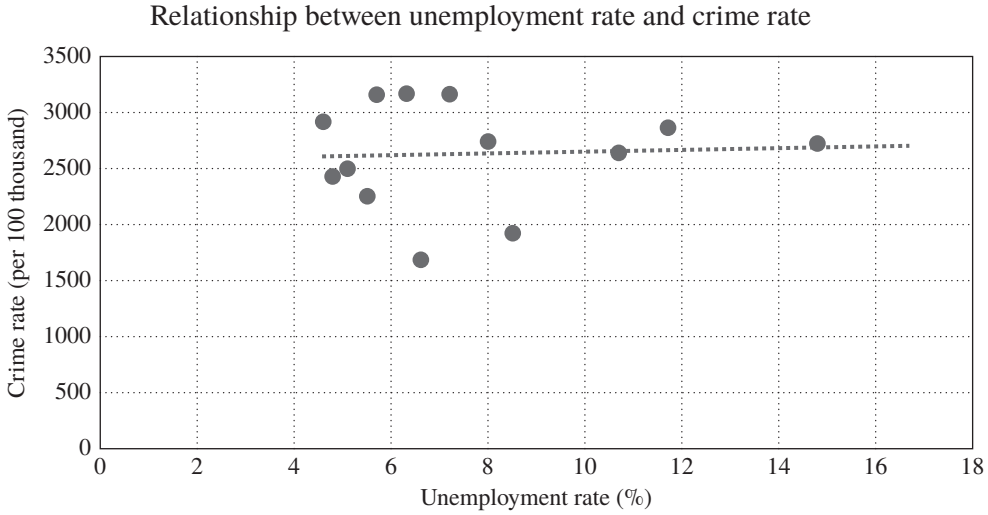

Fig. **9**. A graph showing the relationship between unemployment rate and crime rate
Source: own elaboration.

relation R was calculated, in order to identify the nature and strength of the relationship between the two variables (Fig. 9).

From the graph, a very slight positive trend can be seen, however, the R^2 value of 0.005 is too small, and suggests that the correlation between the two variables does not exist. In addition, due to a low number of sample sizes and a low R^2 value of 0, it can be said that there is no significant evidence to reject the H_0 hypothesis. Therefore, it can be argued that there was no association present between the unemployment rate and crime rate throughout the years.

Even though high unemployment was expected to lead to higher crime rates due to the fact that individuals would be more likely to commit crime acts to seek more income, the results could also be explained by taking into account that high unemployment could slow down the circulation of people and properties, which would lead to people spending more time at their properties and so reducing the suitable targets of criminal acts (Gao, Liu, Kouassi 2017; Jonathan et al. 2021).

Furthermore, the unexpected effect of unemployment on crime rates during the year 2020 could be explained by a Covid-19 pandemic like in J.P. Schleimer et al. (2022) researches. Although many people lost their jobs which lead to an increase of unemployment, imposition of quarantine has also forced people to spend the majority of their time at home, which have resulted in lower crime rates due to the reduction in opportunity of crime.

LIMITATIONS

Due to the fact that a large data sample size from reliable sources was used and appropriate methodologies to process and analyse the secondary data were chosen, the research could be said to be conducted in a reliable and successful manner. The strengths of the study are presented in a table below (Table 1).

However, the research had many limitations that could be removed in order to improve the quality or scope of this research. The limitations of the study and their possible improvements are listed in the table below (Table 2).

Table 1. A table showing the strengths of the studies

Strength	Impacts on the investigation
Large data sample size due to a relatively small size grid	Ensures that the results are more accurate, as the margin of error is smaller. Allowed to create a visual representation of crime distribution patterns in Kaunas.
Referencing similar research papers carried out in other cities	Improves the reliability and validity of the study, as this shows that the methodology and factors were chosen appropriately, and analysis was supported by secondary sources.
Data used was taken from official statistics providers	Use of reliable data helps to ensure that the results are accurate and valid.

Source: own elaboration.

Table 2. A table showing the limitations and suggested improvements for future studies

Limitation	Impacts on the investigation and possible future improvements for repeated studies
Total crime prevalence and rate of all types of crime used, instead of categorizing crime into sub-categories	Different sub-categories of crime could be more influenced by different factors. This relationship was then failed to be seen, as only the influence of factors on the total crime level was tested during this study. This, as well, could have thrown the results off and produce a less significant relationship between the particular factor and the crime level. For further research, the total crime prevalence could be categorized into different crime categories, e. g.: violent crime, property crime.
Dark figures of crime	Dark figures of crime describe the unknown mass of unreported and unrecorded criminal acts (Scott, 2014). Unreported crimes can result in crime statistics being unreliable or inaccurate, so resulting in results not representing the reality. The issue is hard to overcome, as there is no way to predict the exact number of unreported crimes.
Data used for age structure of the society only had the mean age of residents in the area, rather than the percentage of each age group.	Affects the reliability of the results, as the mean values are sensitive to outliers, and do not accurately represent the age composition of the residents living in the area. For future studies, the data of percentage of age groups could be used, to measure whether the places with a higher youth population exhibit a larger crime prevalence. Another limitation of the study is that it does not analyse data outside the city limits of Kaunas, which may have an impact on crime.

Source: own elaboration.

CONCLUSIONS

The mapping of crime prevalence has demonstrated that crimes are the most prominent in the middle of the city of Kaunas and become rarer when moving out.

The analysis of the data of population density and crime prevalence provided sufficient evidence to reject the null hypothesis (H_0) and suggested that there is an association of medium strength between the population density and crime level. This confirms the findings of other research carried out in other cities. The results thus suggest that areas with higher population densities would result in more crimes being committed there. In addition, the map illustrating the locations of businesses suggested that the majority of crimes are committed in the areas that demonstrate characteristics of commercial areas.

The relationship between mean age of the population and crime prevalence showed a bell-shaped curve, and therefore the hypothesis that there is an association between age structure of the population and crime prevalence is partially supported. However due to a lack of data, the full relationship between the age structure of the population and crime prevalence in that area could not be determined.

Lastly, the correlation between the social-economic factor – unemployment rates and crime rates was tested. The analysis failed to provide sufficient evidence to reject the null hypothesis, and therefore it can be argued that there was no association between unemployment rates and crime rates in the city of Kaunas throughout the years 2008 to 2021. Also, unexpected factors (e.g. COVID-19) can lead to changes in the number of crimes.

However, it is important to mention that the relationship between the particular factor and the crime prevalence or rate is a difficult one to determine, as in real life factors always work together and are influenced by a wide range of different circumstances. In addition, the correlation between the two variables does not imply that one caused another, and therefore it cannot be argued that the studied factors directly affected the crime in Kaunas.

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