NATIONAL TECHNICAL UNIVERSITY OF ATHENS
SCHOOL OF RURAL, SURVEYING ENGINEERING AND GEOINFORMATICS ENGINEERING
GEOINFORMATICS POST-GRADUATE PROGRAMME

Master Thesis

Spatial-temporal analysis of traffic accidents in Athens: The case of pedestrians

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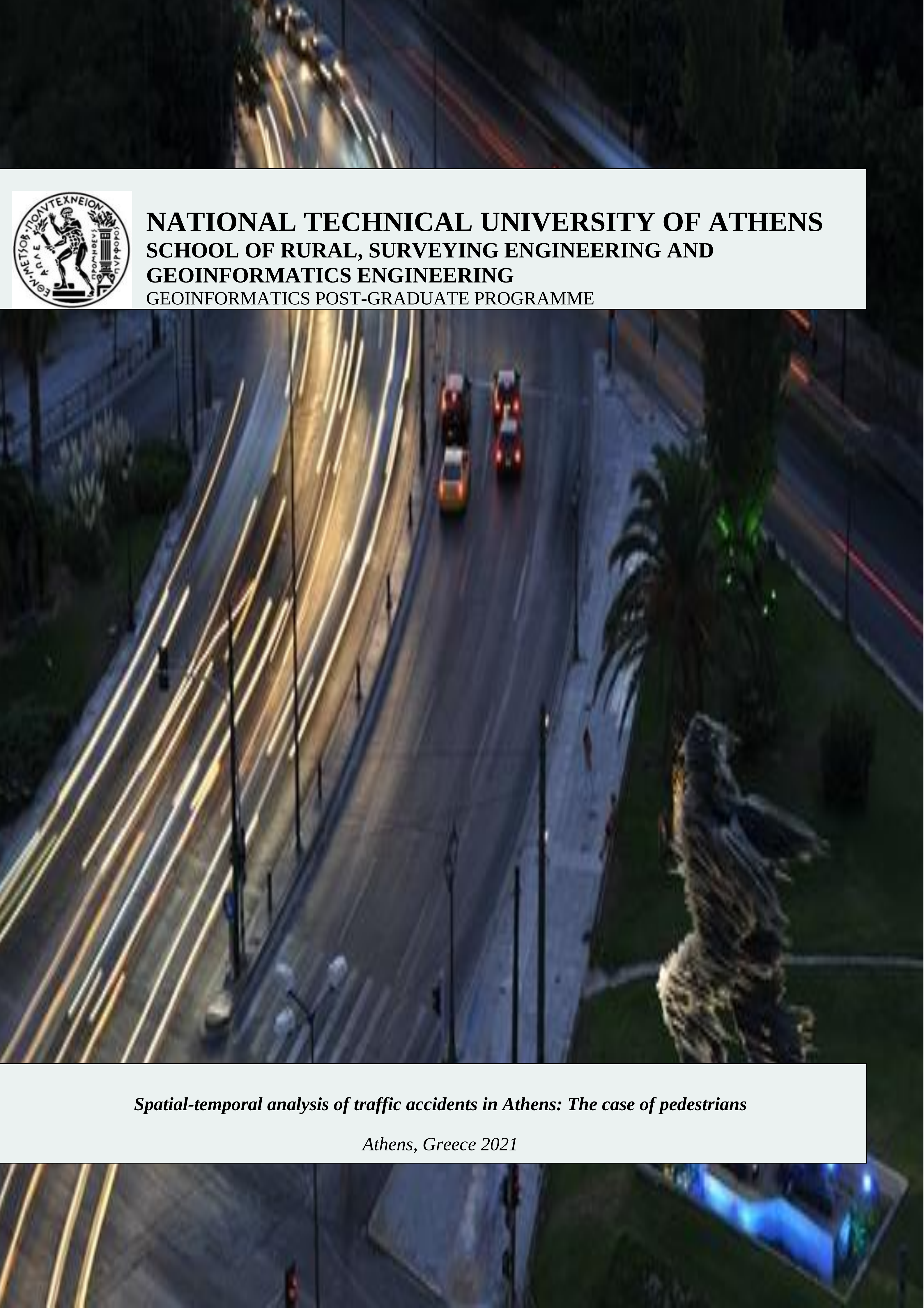

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To my sons Arbi and Einten

Never stop trying…

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Eriola Impersimi

Athens, Greece 2021

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ABSTRACT

This study aims to identify the parameters of the urban morphology that are related to pedestrian traffic accidents, contributing to the literature enrichment. Usually, road accidents are examined as a problem within the road network separately as a single event, while they may be directly connected to the way the surrounding area is formed. Therefore, network analysis was used to identify the relation between the structure of the urban area and the traffic accidents as an outcome of human movement. Specifically, traffic accidents that involved pedestrians were analysed to identify the influence that urban planning might have on them.

The capital city of Greece, Athens, was chosen as the case study and data of 1318 pedestrian accidents through the years 2008-2017 were analysed. Statistical and spatial analysis was used to categorise and classify the road segments based on the severity and the frequency of traffic accidents involving pedestrians. GIS techniques were used to identify those specific areas that present the highest concentration of accidents in both frequency and severity. The results showed that most of the areas concentrating a high number of accidents were located in the very city centre and were persistent through the years. The methodology used for analysing those areas aims in confirming the correlation between the accidents and the way the surrounding area is structured. Therefore, the land use was categorised in transportation data, traffic data and locations related to education and alcohol consumption, which have been reported by previous studies to correlate with pedestrian accidents. Bivariate analysis and Geographically Weighted Regression were used in order to identify the effect of the built environment on the accidents. It was found that there is a correlation between pedestrian traffic accidents and alcohol consumption, mostly in the city centre. In addition, traffic points such as crossings, stops, traffic signals; and transportation points such as bus stops, are related to accidents as well. On the contrary, the education institutes did not show a high correlation with accidents. Finally, an emergency dashboard was created with the aim of presenting a new idea of a real-time platform that can be used by different local and governance services to manage efficiently different incidents that occur in the cities.

Keywords: *Spatial analysis, Network analysis, traffic accidents, built environment, pedestrians, dashboard.*

ΠΕΡΙΛΗΨΗ

Ο συνεχώς αυξανόμενος πληθυσμός των πόλεων, έχει επιφέρει τα τελευταία χρόνια την άμεση ανάγκη για εύρεση λύσεων οι οποίες επικεντρώνονται περισσότερο στο περιβάλλον και τους ανθρώπους αφήνοντας περισσότερο χώρο για επιλογές μεταφορών φιλικότερων προς το περιβάλλον και την υγεία, όπως το ποδήλατο και το περπάτημα. Οι βιώσιμες και "έξυπνες" πόλεις έχουν ώς στόχο την αξιοποίηση της έξυπνης τεχνολογίας προκειμένου να αναπτύξουν τεχνικές προστασίας του περιβάλλοντος και να βελτιώσουν την ποιότητα ζωής των κατοίκων τους. Για να επιτευχθεί αυτό, ωστόσο, χρειάζονται ριζικές αλλαγές στον τρόπο σχεδιασμού των πόλεων οι οποίες μέχρι πρότινος είχαν ως επίκεντρο το αυτοκίνητο. Η οδική ασφάλεια, όμως παραμένει ένα κύριο ζήτημα σε παγκόσμιο επίπεδο το οποίο χρήζει άμεση αντιμετώπιση. Σύμφωνα με πρόσφατα στατιστικά στοιχεία τα τροχαία ατυχήματα συνεχίζουν να αποτελούν κύρια αιτία θανάτου. Επιπλέον, οι πεζοί ως οι πιο ευάλωτοι χρήστες του οδικού δικτύου είναι εκείνοι για τους οποίους πρέπει να λαμβάνονται τα περισσότερα μέτρα ασφαλείας.

Η παρούσα εργασία έχει ως στόχο την ανάλυση οδικών ατυχημάτων των πεζών και τον προσδιορισμό των παραμέτρων του δομημένου περιβάλλοντος οι οποίοι σχετίζονται με αυτά. Για την επίτευξη του σκοπού αυτού χρησιμοποιήθηκαν διάφορες τεχνικές ανάλυσης σε περιβάλλον Γεωγραφικού Συστήματος Πληροφοριών (ΓΣΠ).

Η έρευνα επικεντρώθηκε στην στατιστική και χωρική ανάλυση δεδομένων 1318 ατυχημάτων πεζών τα οποία είχαν συμβεί μεταξύ του 2008-2017 στην πρωτεύουσα της Ελλάδας, την Αθήνα. Το χωρικό πρότυπο του φαινομένου εξετάστηκε τόσο συνολικά, όσο και ειδικά ανά κατηγορία ατυχημάτων ανάλογα με την σοβαρότητα του οδικού ατυχήματος.

Οι τεχνικές ΓΣΠ χρησιμοποιήθηκαν για τον προσδιορισμό των συγκεκριμένων περιοχών που παρουσιάζουν τη μεγαλύτερη συγκέντρωση ατυχημάτων τόσο σε συχνότητα όσο και σε σοβαρότητα. Πιο συγκεκριμένα, χρησιμοποιήθηκε η ανάλυση δικτύου για τον προσδιορισμό των τμημάτων του οδικού δικτύου που παρουσιάζουν την μεγαλύτερη συγκέντρωση ατυχημάτων πεζών και χαρακτηρίζονται ως επικίνδυνα τμήματα, των τμημάτων εκείνων με λίγα ατυχήματα ή και καθόλου ατυχήματα. Η ανάλυση αυτή πραγματοποιήθηκε και διαχρονικά προκειμένου να αναδειχτούν τα τμήματα του οδικού δικτύου που παρουσιάζουν διαχρονικότητα ή ένταση, αποτελούν νέα εστία ή παλιά εστία ατυχημάτων. Τα αποτελέσματα έδειξαν ότι οι περισσότερες από τις περιοχές που συγκεντρώνουν μεγάλο αριθμό ατυχημάτων πεζών βρίσκονταν στο κέντρο της πόλης και ήταν επίμονες με την πάροδο των ετών. Η μεθοδολογία που χρησιμοποιείται για την ανάλυση αυτών των περιοχών στοχεύει στην επιβεβαίωση της συσχέτισης μεταξύ των ατυχημάτων και του τρόπου με τον οποίο είναι δομημένη η γύρω περιοχή. Ως εκ τούτου, η χρήση γης κατηγοριοποιήθηκε σε δεδομένα μεταφοράς, δεδομένα κυκλοφορίας και τοποθεσίες που σχετίζονται με την εκπαίδευση και την κατανάλωση αλκοόλ, τα οποία έχουν αναφερθεί από προηγούμενες μελέτες ότι συσχετίζονται με ατυχήματα πεζών. Η διμεταβλητή ανάλυση και η γεωγραφικά σταθμισμένη παλινδρόμηση χρησιμοποιήθηκαν για να προσδιοριστεί η επίδραση του δομημένου περιβάλλοντος στα ατυχήματα. Διαπιστώθηκε ότι υπάρχει συσχέτιση μεταξύ τροχαίων ατυχημάτων πεζών και κατανάλωσης αλκοόλ, κυρίως στο κέντρο της πόλης. Επιπλέον, σημεία κυκλοφορίας όπως διαβάσεις, στάσεις, σήματα κυκλοφορίας και σημεία μεταφοράς, όπως στάσεις λεωφορείων, σχετίζονται με τα ατυχήματα. Αντίθετα, τα εκπαιδευτικά ιδρύματα δεν παρουσίασαν υψηλή συσχέτιση με αυτά. Τέλος, δημιουργήθηκε ένας πίνακας παρακολούθησης έκτακτων περιστατικών με στόχο να παρουσιαστεί μια νέα ιδέα πλατφόρμας, η οποία παρακολουθεί σε πραγματικό χρόνο διάφορα περιστατικά στην πόλη και χρησιμοποιείται από τοπικές υπηρεσίες για την αποτελεσματική διαχείριση των περιστατικών.

Λέξεις κλειδιά: *ατυχήματα πεζών, στατιστική ανάλυση, χωρική ανάλυση, ανάλυση δικτύου, γεωγραφικά σταθμισμένη παλινδρόμηση, δομημένο περιβάλλον, πίνακας παρακολούθησης έκτακτων περιστατικών.*

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1. INTRODUCTION

The rapid growth of our societies has led to complex forms of urbanism. However, these last years, transportation planning is taking a U-turn to more sustainable, environmentally-friendly planning, providing more space for healthy transportation options (i.e. walking, cycling). Especially now, the trend toward alternative travel methods has been deeply supported and inspired by the pandemic situation. Many big cities around the globe are taking different measures for banning vehicles from certain areas like city centres. This prospect of car-less and careless cities seems to be an envision of more nature-friendly cities rather than just a pandemic trend. Due to the disadvantage, the pedestrians have towards the other means of transport when involved in traffic crashes; it is of great importance to improve the road safety for pedestrians in particular.

Road safety is of the most important factors that traffic planners take into consideration while building road networks. However, given the fact that road planning influences urban planning in general, it is unavoidable that urban forms have an impact on road safety.

This thesis purpose is to identify whether there is a connection between traffic accidents and the built environment. Specifically:

The **Second Chapter** refers to the different research that has taken place globally to approach similar issues and provide knowledge in the object of this diploma thesis. First of all, reference has been made to the studies that analyse urban morphology and how urban planning may affect road safety. As a consequence, related concepts are mentioned with special reference to network analysis and the way it is related to accidents. In addition, different types of accidents are described providing statistics on their frequency and severity. Moreover, pedestrian' characteristics were described along with their behaviour and movement within the road network. Finally, reference is made to similar studies.

In the **Third Chapter**, the methodology followed for approaching this issue is introduced. Firstly, the case area of the research is presented, analysing the characteristics which are considered important for the further process. In addition, the methodology refers to the procedure followed, as well as the technique and tools used to proceed and collect the results of the analysis. Finally, reference has been made on data collection, quality and organisation.

The **Fourth Chapter** includes the data analysis. The statistical analysis conclusions are presented, configuring the identity of the sample. Furthermore, the results of spatial and network analysis are presented and visualised. Lastly, the main conclusions of the chapter are captured, and a dashboard containing collision data is presented with the aim of developing a platform that manages the different types of incidents in real-time.

In the **Fifth** and final **Chapter** are listed the conclusions of the research as well as the factors of the built environment that have been identified to play a significant role in pedestrian accidents. Moreover, some suggestions have been made for future research.

2. THEORETICAL BACKGROUND

2.1. Introduction

The demand for more environmentally friendly, sustainable and resilient cities is now higher than ever before. Climate change was the major problem of our societies, and efforts to save the planet have started long ago. However, the Covid-19 pandemic set even higher demands making it crucial for the countries to have smarter cities for their residents. This means that first of all, cities have to make changes to their urban infrastructure, ensuring that their further development is placed on the right foundations. One thing found during the pandemic is the demand for more space for safe walking. All these years planning was car-centred providing wider, bigger roads and parking areas for cars making pavements disappear in certain areas of the cities. As this pattern tends to change, it is to be considered how the improvements of urban planning are beneficial as well as safe for pedestrians. While many studies deal with urban morphology and road safety, very little has been written about the connection these two subjects might have.

This chapter refers to the different studies written about urban morphology and planning. In addition, studies about road safety are mentioned along with research that has connected these subjects. Furthermore, different ways and methods used for analysing such subjects are listed, with special reference to studies that used network analysis as an approach. Studies about pedestrians' characteristics and movement behaviour are critical in understanding their role in the general network. Finally, statistics about accidents are provided, along with their severity and frequency.

2.2. Urban Morphology and Smart Sustainable Cities

Cities are living organisms that adapt and evolve in the transformation processes and characteristics of each era. Hillier (2012) refers to them as complex socio-technical systems that consist of two sub-systems: the physical that contains buildings linked by streets, roads and infrastructure, and the human consisting of movement, interaction and activity. The two sub-systems continually influence one – another and share a dependent relationship (Attig, 2019). During the past century, globalisation, population growth and fast-changing and developing technologies had a massive impact on the societies' functionalities. The problems that today's cities face are inextricably linked to concerns about planet sustainability, citizens' well-being and financial sustainability.

The concepts of "sustainable" and "smart" cities have been introduced many years ago, and the studies about them have increased a lot during these years. While sustainability is a concept that describes the need for more environmentally friendly cities, the meaning of "smart" has not been quite clear (Hollands, 2008; Angelidou, 2015; Ahvenniemi et al., 2016). More specifically, Hiremath et al. (2013) and Ahvenniemi et al. (2016) define sustainability as a balance that is achieved between the development of the urban areas while protecting the environment and taking into consideration social infrastructure and transportation, employment, income, shelter and basic services. The development of environmental assessment tools and frameworks helps the built environment and transport to achieve sustainability goals. On the other hand, the term "smart" city lacks a universally accepted definition (Li et al., 2019). The existing literature refers to them as characterised by a mix of technological development, with a focus on electronic and digital technologies (Komninos, 2008), or as a rather complex system (Portugali, 2000; Li et al., 2019).

Lately, cities have been shifting from sustainability frameworks to smart city goals (Ahvenniemi et al., 2016). The focus is mainly on providing new, modern technologies that make cities "smarter", rather than focusing on environmental sustainability indicator measurements. Smart cities lack environmental indicators, but the general goal is to provide technologies that improve sustainability. To limit the gap between sustainable and smart cities, Ahvenniemi et al. (2016) propose the redefinition or further development of smart cities frameworks and the use of impact indicators along with output indicators that can measure the assessment of smart cities. They also propose the use of the term "smart sustainable cities" in order to define the cities of the future.

The technologies used in smart cities can have a significant impact on the management of public transport, safety, utility management, waste management, traffic, parking and the environment (Carter et al., 2020).

Figure 2.1: Smart cities (www.forbes.com)

2.2.1. Urban and Transportation Planning

Urban morphology studies the forms and types of human settlements through time. It aims to understand the way that urban forms of cities have transformed over time, the spatial patterns they have in different scales and define their physical characteristics (Chen, 2014). While studying the complexity of human settlements as individual entities, conclusions can be drawn on the way they interact and correlate as a whole (Oliviera, 2016).

In large cities, the urban spatial structure appears to be getting more complex due to the population growth, the increasing amounts of income that enable individuals to live more diverse lifestyles and the engagement to travel more. The impact of these trends has visible effects on urban activity and development, as cities appear to have a more polycentric structure (Zhong et al., 2014)

In a study of 1999, Miller mentions that the transportation problems are radically different from those faced in the past century, as the increase in the transportation system congestions is unavoidable (Downs 1992, Hanson 1995). New methodologies to address the problem should be developed, as the old ones will not work (Giuliano, 1995).

However, the situation nowadays remains quite difficult. Individuals are still relying mostly on cars for their transport, due to lack of alternative options in the cities. The number of vehicles continually grows, and the problems due to the traffic jam remain high in the road networks, making a negative impact on public transport as well. Apart from the huge problems of urban nuisance and pollution, cars remain one of the main causes of death due to the high percentage of road accidents.

Greece, in particular, has a continually increasing number of cars and their use compared to other means of transport, is dominant. The public means of transport fail to manage the ever-increasing traffic (Liogka, 2020). The most common issues that occur are traffic jams, lack of car parks, a high percentage of road accidents and difficulties in using sustainable means of transport like cycling and walking. These issues raise concerns about road safety.

2.2.2. Road Safety

Many studies and research have focused during the years on road safety, especially during the last decade where the urge for more sustainable transportation and urban planning increased. Most of the research focuses on the identification of the vulnerable locations of the network that tend to concentrate most accidents and create the so mentioned hotspots. The most complex locations tend to be identified in urban areas, mostly due to the many land uses that coexist at the same location. Geographic Information Systems (GIS) are very much used for such analysis purposes, due to their advanced methods and tools of spatial and statistical analysis, along with advanced visualisation of the results.

Many methodologies and tools exist that can be used in spatiotemporal analysis, and the choice depends on the study purpose. Molla et al. (2014) used the Kriging method for the identification of the road accident hotspots in North Dakota during the period 2001-2010. Their geostatistical and tracking analyst model, based on single linkage method clustering, spotted the counties with the highest accident-prone and concluded facts about traffic safety improvements.

In addition, studies like those of Steenberghen et al. (2003), Anderon (2007), Prasannakumar et al. (2011) and Ivan and Haidu (2012), have tried to identify the most vulnerable areas of the network, using methods like kernel density estimator, mean centre, or standard deviational ellipse to highlight the distribution of the fatalities and collisions. Specifically, Ivan and Haidu (2012), while analysing accidents that occurred in a Rumanian city from 2010 to 2012, used the mean centre as well as standard deviation and standard deviational ellipse, which showed that the accidents were concentrated along the main road of the city network.

Prasannakumar et al. (2011) used Moran’s I method of autocorrelation, Getis-Ord Gi statistics as well as Kernel density for the assessment of spatial clustering of different types of accidents and hotspots spatial densities in a South Indian city. Their dataset was indicated to be clustered, and their results were effective, as could be used for the traffic management and reductions of accidents of the city.

Moreover, Erdogan et al., 2017, while analysing data from accidents that occurred in a city of Turkey, used Kernel Density Analysis to calculate the density of the accidents along the city highway. It was found that the accidents' percentages were higher during weekends, the evening hours are the most dangerous, and most fatalities occur during midnight.

Other studies like those of Noland and Quddus (2004), Erdogan (2009) and Hong et al. (2016) have used regression for the correlation of the road accidents to other variables. Those who performed their analysis in GIS, used geographically weighted regression, while the variables used are related to the road network characteristics, the number and type of vehicles, and different other socio-economical characteristics of the case area.

Attig (2019) used space syntax analysis to investigate the difference between a conventionally used street segment model and a natural street model for measuring traffic accidents and crime. He concluded that the model of the natural street shows better proximity to the events and is a viable method for understanding the human interactions with the physical environment.

Many pieces of research and studies have been conducted in Greece about road safety, using a wide range of methods. Yannis et al. (2017) used lognormal regression for the analysis of 59.316 accidents that had occurred in Greece. They developed many different models on the severity of the accidents for the different kinds of vehicles used. Moreover, they examined three different types of accident severity, the number of fatalities normalised by the total number of vehicles involved, the number of severe injuries normalised by the total number of vehicles involved, and the number of slight injuries normalised by the total number of vehicles involved. They concluded that parameters like weather conditions influence the severity of the accidents no matter the vehicle used. Moreover, the accidents that occur during night hours, as well as those during bad weather conditions, are more likely to be more severe, while the type of collision has a constant influence on the severity.

Machairas (2017) analysed the fatalities of road accidents that had occurred during the period 2011-2015 in the country of Greece on a prefecture scale and the Attica region on a municipality scale. To identify the parameters that correlate with the fatalities, he used ordinary least squares (OLS) and geographically weighted regression (GWR). The conclusion showed that parameters like type and characteristics of the road network, economy and land use were highly correlated with the accident fatalities. It was also concluded that the main parameters found in country scale analysis were not the same as those found in the Attica region.

Other studies like the one of Melidoniotis (2013) were concentrated in a specific area of Greece. This study analysed the road accidents in Crete from 2001 to 2012, using spatial analysis methods like Moran's I, Regression, co-Kriging and Interpolation, to identify the hotspots of the network and the risk parameters. Among the conclusions, the study showed a tendency in the increase of incidents in the following years, while the month that most of the fatalities occurred was found to be June. The most dangerous hours of the day were 12.00-18.00 and 18.01-00.00. Finally, the highest percentage of persons involved in fatalities were males, with the age average being 39 years old.

During another study, Liogka (2020) used spatial analysis and space syntax analysis for the accidents that had occurred in Athens, Greece, between the years 2008 – 2017. She examined the spatial pattern of the phenomenon by analysing the data into different categories, depending on the severity of the accident, the road user type and network classification, while space syntax was used for the investigation of the relationship between the spatial configuration of urban network and the traffic accidents. Space syntax analysis showed a correlation between syntax choice radius of 5000m and the different types of accidents, as the radius is correlated with vehicles movement. The study also identified the roads within the traffic network, where the accidents are more likely to occur regardless of the network user type (e.g., driver, pedestrian etc.).

Finally, Kostellou (2020) used three different methods for processing accident data from accidents that occurred in Athens between 2011-2015. The methods used were those of explanatory data analysis, spatial autocorrelation and unsupervised classification. She concluded that regardless of the method used, the most problematic areas where most accidents occurred were located in the municipalities of the metropolitan area of Athens.

2.2.3. Network Analysis for transportation and the built environment – Similar approaches

Network Analysis is widely used for transportation research. Most of the studies, however, focus on analysing data of vehicles' crashing. Some studies have also tried to correlate network analysis with the built environment, but due to the complexity of pedestrian movement, research is only focused on specific methodologies and factors that might have the highest impact. Most of the studies use Kernel Density Estimation in order to identify the density of accidents' locations, while some others prefer Network analysis and concentrate mostly on the problematic segments of the network. Anderson (2006) compared three different methodologies used for measuring road accidents hotspots. She concluded that network analysis and census tracks are more network based and used for determining the specific problematic segments of the network. Kernel density on the other hand, can determine the spread of the risk of an accident.

Additionally, Dai and Jaworski (2016) examined the influence of built environment on pedestrian crashes with a network-based approach. They used data of a period of seven years of accidents that occurred in Georgia, United States. Hotspots were located with a network-based kernel density technique, while bivariate and binominal models were utilized to examine the built environment influence. The results showed that a high density of pedestrian accidents was spotted near public transit stops and areas with more public transit users. They emphasized the need for more extensive prevention campaigns in the problematic areas, as well as planning more pedestrian-safe environments in the future.

Moreover, Mohamed et al. (2012) used clustering regression techniques to determine factors of the built environment that influence pedestrian-vehicle crashes. They concluded that factors like pedestrian age, driver age, vehicle type, driver alcohol involvement, lighting conditions and several other built environment characteristics had a high influence on fatal crashes.

Saelens and Handy (2008) with a review on previous research aimed at conclusions about correlations between the built environment and walking. They found differences in the relation between the environment and the type of walking. Positive relations were found between walking for transportation and density, distance to nonresidential destinations and the mix of land uses; equivocal findings were identified as far as network connectivity, parks and open space, and personal safety are concerned, while recreational walking did not appear to have clear results.

Other studies relate the severity of traffic accidents with both built environment characteristics and pedestrian characteristics (Aziz et al., 2012; Mohamed et al., 2012). Aziz et al. (2012) found that older individuals are more likely to be fatally injured. They also examined many built environment variables but found that only network connectivity and transit access influence non-fatal injuries and were negatively associated with minor injuries. Their study underlined the need of considering environmental characteristics while planning for pedestrian safety.

Finally, Zahabi et al. (2011) investigate the effects of road design, speed limit and factors on the injury severity levels of pedestrians along with the built environment. They concluded that accidents occurring at intersections near educational institutes have a lower pedestrian severity. Furthermore, factors like the presence of major roads, darkness, median income, mixed land use and park presence within 10 meters show an increase in pedestrian collision severity.

In order to better understand the correlations between the built environment and pedestrian accidents, it is of utmost importance to examine how pedestrians react and move through the road network and the built environment.

2.3. Pedestrians

When it comes to road safety, pedestrians are the more vulnerable users of the traffic network and show a very high percentage of road accidents and fatalities. There are many factors to be considered that affect road users' safety, but as the biggest percentage of car accidents that occur involve pedestrians, an attempt to lower pedestrian accidents number would have a greater impact on road accidents in general (Andrikopoulou, 2019). Tomai and Kavouras (2004) refer to humans as spatially referenced" objects" that continually interact with space. Thus, it is essential to understand pedestrians' behaviour and reactions to the built environment and network changes.

Figure 2.2: Pedestrians as vulnerable road users

2.3.1. Pedestrians' characteristics and movement behaviour

As this study aims at identifying the parameters of the built environment that affect pedestrian accidents, it is crucial to refer to related studies that have focused on the investigation of pedestrians' movement and their behaviour while walking, and factors like speed, network parts preferred to cross, as well as the characteristics of their route.

Figure 2.3: Pedestrian multi crossing (www.google.com)

Since the 90's many countries have developed different types of transport policies and attempts to promote walkability as a means of transport. These attempts aim in limiting the use of vehicles as a means of transport, to reduce congestions and environmental problems, as well as to extinguish health problems related to obesity. Although many studies during the years have focused on pedestrian movement and behaviour, this has not been an issue when it comes to the design of traffic models and stimulation. According to Batty (2001), pedestrian movement is ignored firstly due to the origin of transport planning, which was, and in many countries still is, car-focused, and secondly due to the traffic analysis scale that includes a very high number of people that move in different zones, making detailed analysis difficult.

Deamen (2004) classified pedestrian behaviour in three different levels, the strategic, the tactical and the operational. On the strategic level, the pedestrian decides which activities to perform and whether they can be accessed by walking. On the tactical level, short-term decisions are made that lead to fulfilling the goals set at the strategic level. The activities are carried out in different orders, and the borders between these two levels are not quite clear (Andrikopolou, 2019). Finally, the operational level includes instant decisions that affect pedestrian walkability, speed, or their behaviour and decisions of movement in general (e.g., stopping and waiting before crossing the road). The operational level decisions are affected by the choices made on the strategic and tactical levels. A fast-walking pedestrian (operational level), following a route without traffic signals (tactical level) aiming to walk to his destination (strategic level), is an example that clearly describes the coexistence of these three levels (Andrikopoulou, 2019).

All these factors affecting pedestrian’s movement are very crucial for urban and transportation planning. A study conducted in 1963 by Buchanan et al., determines the road network conditions that have an impact on a pedestrian road crossing, the delays that might occur due to traffic jams and even the sidewalk width that correlates with the delays of pedestrian traffic levels. Other studies during the past years are focused on the improvement of simulation models for pedestrian movement. Although they have rapidly evolved, it is still more to be done. Pedestrian movement models include different types of analysis, while in most of them, pedestrians are modelled as individual entities described by their special characteristics. The data quality resulting from these models depends on the quality of the behavioural data of the entities.

Other factors that are important and have to be considered are the decisions about the route beginning and destination, as these are quite different from the decisions made in the case of vehicles, respectively. The route choices in the case of the pedestrians have a higher degree of freedom, while the vehicles are restricted from the network and the traffic rules. On the other side, the route length of vehicles is not as restricted as in the pedestrians’ case. Pedestrians’ characteristics are more complex in many aspects compared to those of vehicles and other means of transport. Their speed and movement directions, the distance between other pedestrians and the distance from vehicles while deciding about network crossing are highly correlated with factors like land use, weather conditions, day and hour, as well as other demographic characteristics.

Moreover, studies in pedestrian movement behaviour concluded that their movement characteristics are defined quite differently as far as it concerns roadside walking and road crossing, respectively. It is referred that the average speed of movement on the roadside depends on the presence of other pedestrians, meaning that the pedestrian density correlates with pedestrian speed. Other factors that affect pedestrians’ speed are age, gender, route type and destination, hour and day (Ishaque et al., 2007).

Additionally, Hoel (1968) and Harrell (1990) refer to weather conditions like low temperatures that have an impact on pedestrians’ movement. These studies concluded that the movement speed increases during very low temperatures.

Other environmental factors that have an impact on pedestrians’ speed and movement are related to conditions of the built environment (e.g., large roadsides, pedestrian crossings, under or overground walkways, etc.).

The pedestrians’ speed differs in the case of road diffusion, while it is correlated with characteristics and factors like age, gender, route type, physical condition, free space between vehicles, crossing types and traffic signals. Moore (1953) refers that pedestrians that tend to cross the road at small gaps between vehicles increase their speed. In addition, Cohen (1995) concluded that males tend to choose road crossing in smaller gaps between the vehicles rather than females regardless of their age, except from the group age of 31-45 where the differences were minimal between the genders. In any case, the crossing speed depends on the risk that the pedestrian is willing to take while crossing in small gaps. Thus, pedestrians crossing in smaller gaps face higher risk and therefore develop higher speeds.

Other behaviours of pedestrians are straightly related to the built environment and other parameters and information that might affect the concentration. Alsaleh et al. (2017) mention that the distraction at pedestrians is on the same level as the other users of the transportation network, especially due to the high usage of electronic devices. The results of walking under distraction are similar to those of driving under distruction (Hyman et al., 2010; Sarkar et al., 2011; Andrikopoulou, 2019). Finally, during the EC SafetyNet project between the period 2005-2008, in-depth data were collected from the accidents in six European cities, and a database was formed with detailed information that included among others, the causation. One of the conclusions of data analysis was the fact that missed observations, decision errors and inadequate plans are a result of distraction in pedestrian accidents. Figure 2.1 shows the results of the project with the most frequent links between causes and pedestrians. The links are found to be 101 in total.

Table 2.1: Ten most frequent links between causes-pedestrians (SafetyNet Accident Causation Database 2005-2008/ EC, Date of query: 2010)

Links between causes	**Frequency**
Faulty diagnosis - Information failure (between driver and traffic environment or driver and vehicle)	16
Observation missed - Inadequate plan	10
Observation missed - Distraction	10
Observation missed - Temporary obstruction to view	10
Inadequate plan - Psychological stress	5
Inadequate plan - Insufficient knowledge	5
Decision error - Distraction	4
Inadequate plan - Distraction	4
Inadequate plan - Under the influence of substances	4
Observation missed - Faulty diagnosis	3
Others	30
Total	**101**

Walking under destruction results in many problems on road safety, increasing the risk of road accidents.

Figure 2.4: Walking and electronic device usage (www.gooogle.com)

2.3.2. Road safety and pedestrians

Road safety is a current issue faced in every country and especially in every big, busy city like Athens. Road accidents that occur every year prove that road safety must be considered first. The last statistical reports on accidents in Europe showed that Greece had a decrease in the trend of accidents that lead to injury or death, while there are still countries having positive trends with Spain in the first place.

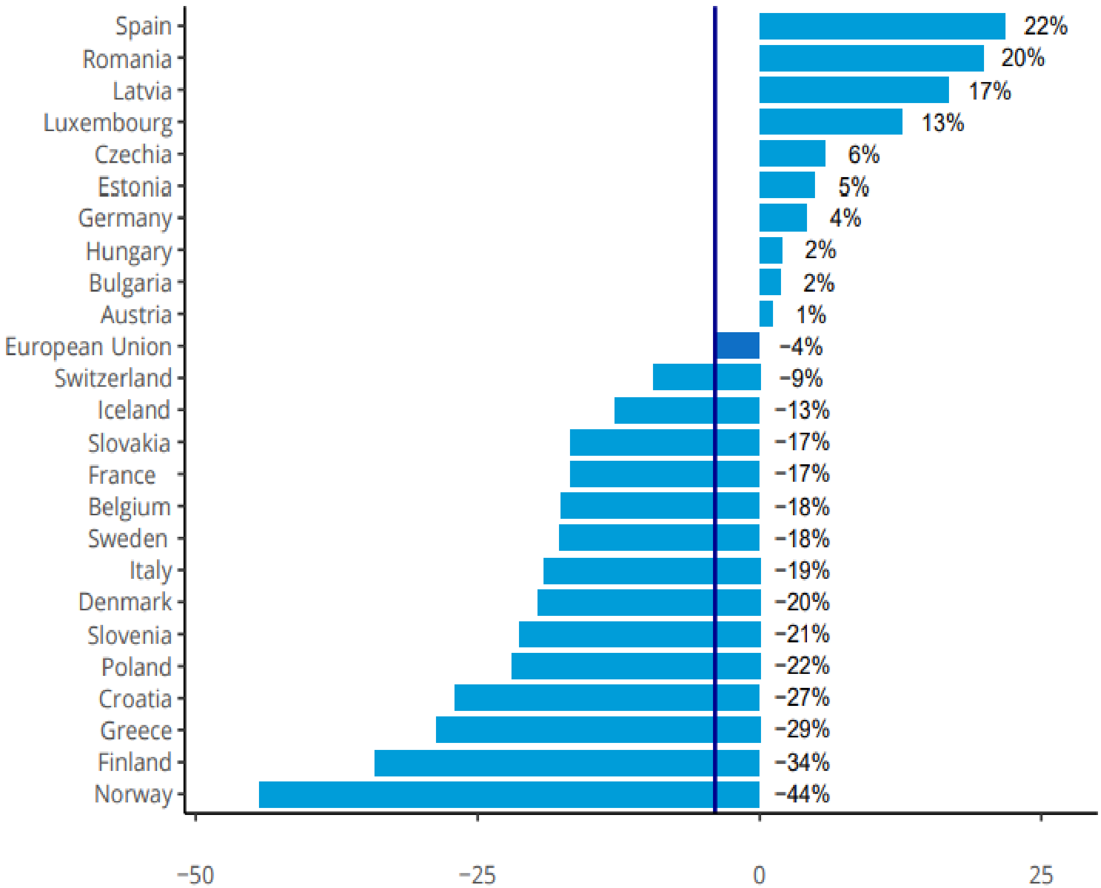


Figure 2.5: Trend in the number of crashes leading to injury or death. [| Mobility and transport (europa.eu)]

Furthermore, data on trends of fatalities showed that Greece is in second place among European countries with a high percentage of 45% decrease in the fatalities, while the Netherlands shows an increase in the tendency of the accidents leading in fatalities (figure 2.6).

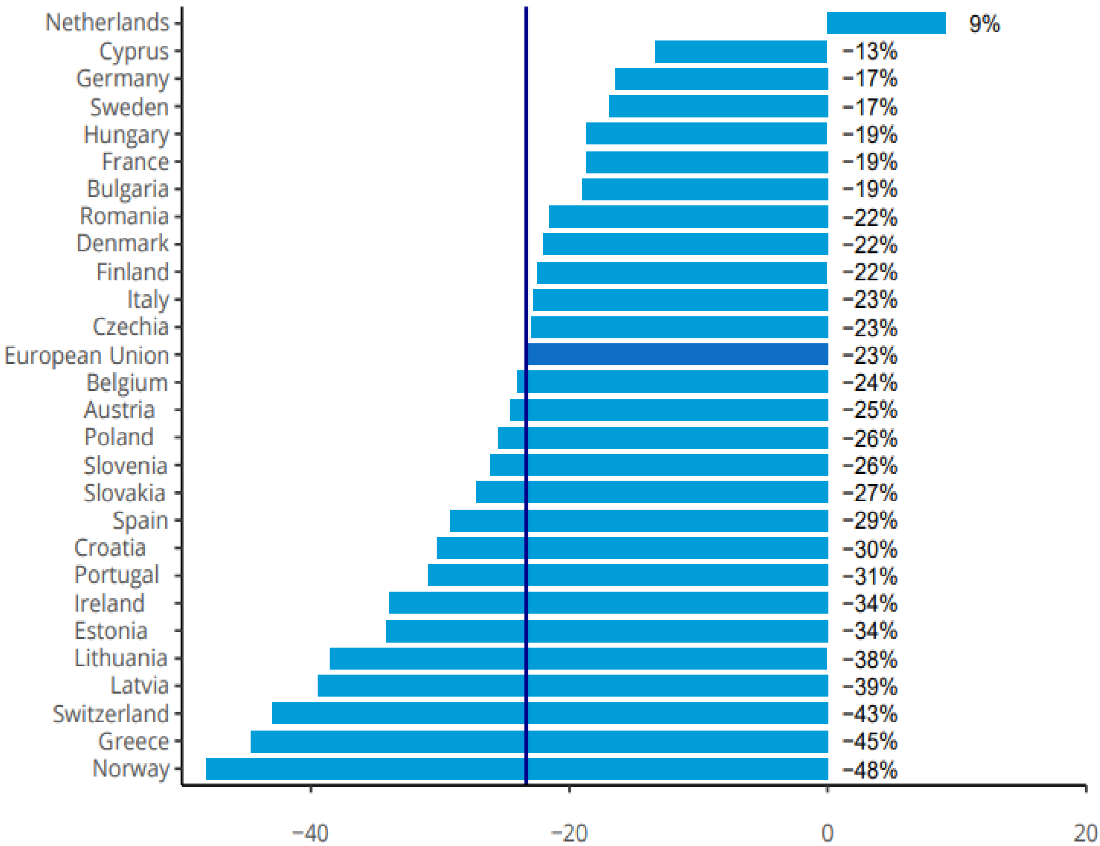


Figure 2.6: Trend in the number of fatalities | Mobility and transport (europa.eu)

Figure 2.7 shows Greece among some selected European countries and their relative number of fatalities throughout the years.

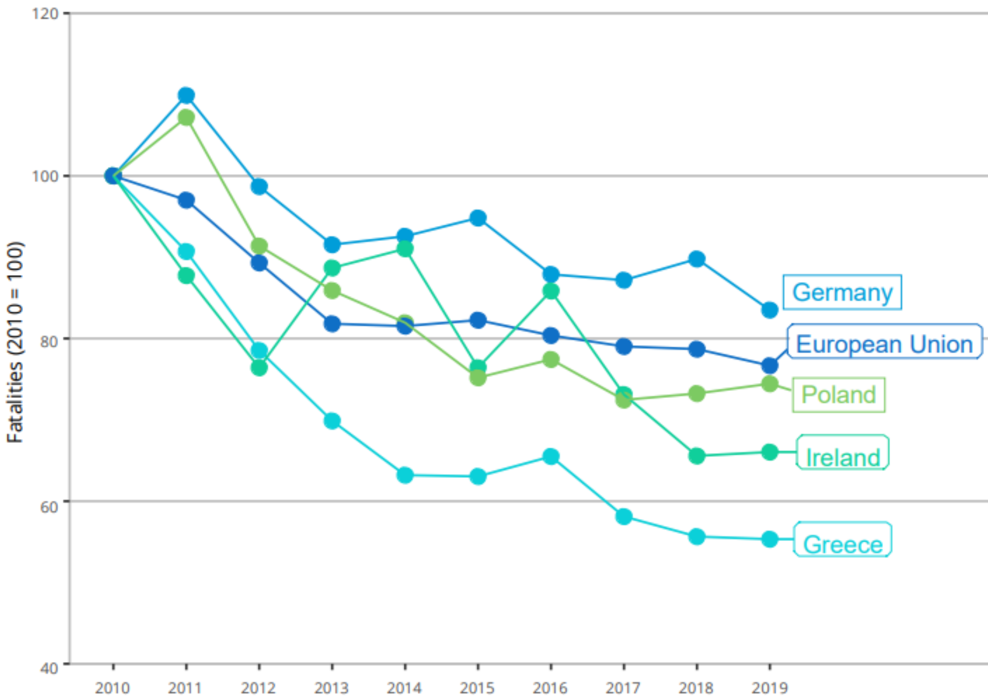


Figure 2.7: Relative number of fatalities by selected countries 2010-2019 | Mobility and transport (europa.eu)

As mentioned previously, pedestrians are the most vulnerable users of the network, and they face a high risk of severe injury or fatality while involved in accidents. Moreover, the number of pedestrian fatalities during collisions is constantly increasing, making it clear that the safety measures for pedestrians are insufficient. Despite all, 21% of road fatalities in Europe are pedestrians (European Road Safety Observatory, 2018). Figure 2.8 shows the percentage of total road fatalities between 2007-2016 compared to the number of pedestrian fatalities during the same period. Many studies have been conducted to raise the problem and suggest solutions, but still, more has to be done as far as pedestrians' safety is concerned.

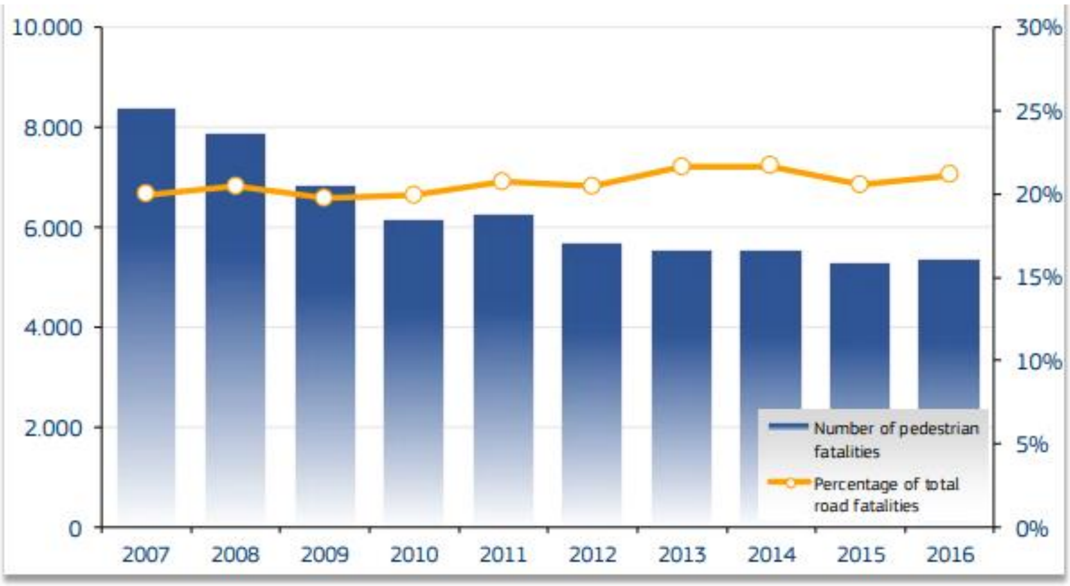


Figure 2.8: Number of pedestrian fatalities and percentage all road fatalities, EU, 2007-2016 (Care database, data available in May 2018)

During the study of 2016 World Health Organisation (WHO) concluded that the number of pedestrian's injuries was as high as 25million, while the number of fatalities was 625.000 (World Health Organisation, 2016). Other studies showed that the number of pedestrians' accidents during this decade has increased compared to a general number of road accidents. Studies in the USA showed that the percentage of pedestrians' fatalities had increased to 16% compared to other groups fatalities, while it is confirmed that every 1,5 hours, a pedestrian fatality occurs (NHTSA, 2018). In addition, the higher percentage of pedestrian accidents includes individuals of age >65. Some of the factors that affect the casualties are the time that pedestrians need to spend crossing the network, and the distance walked. In 2004 the Surface Transportation Policy Project mentioned that 8,6% of the routes are done through walking. Results from the same project showed that in every 100million miles of pedestrian routes, the loss index was 15 times higher than the equivalent of drivers. Figure 2.9 shows the diurnal pattern in the number of fatalities by transportation mode for the European Union (2019). Pedestrian fatalities appear to have higher percentages during the afternoon hours, and in any case, they have higher percentages of fatalities compared with bicycles, mopeds and motorcycles.

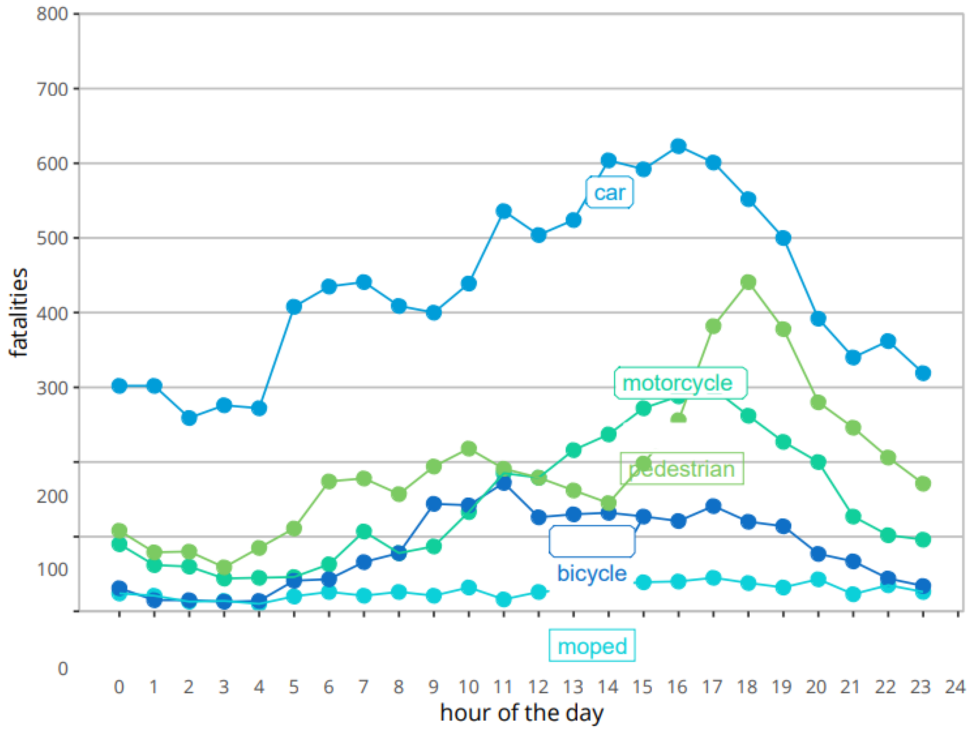


Figure 2.9: Diurnal pattern in the number of fatalities by transport modes for the European Union 2019 | Mobility and transport (europa.eu)

Table 2.2 shows the number of pedestrian fatalities in the countries of the EU during the period 2010-2019. Greece shows to have had a reduction in the fatalities until 2017; however, this has changed during 2018 and 2019 where the fatalities have increased.

Table 2.2: Annual number of pedestrian fatalities by country 2010-2019 | Mobility and transport (europa.eu)

country	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Belgium	108	115	117	109	107	94	81	95	74	92
Bulgaria	174	149	135	108	156	164	118	157	123	154
Czechia	168	176	163	162	130	150	130	129	142	111
Denmark	44	33	31	34	22	27	36	20	30	30
Germany	476	614	527	561	527	545	500	489	464	421
Estonia	14	26	29	23	26	24	22	10	12	11
Ireland	44	47	29	31	41	31	35	-	-	-
Greece	179	223	170	151	125	128	149	118	146	145
Spain	471	380	370	371	336	367	389	351	386	381
France	485	519	489	465	499	466	553	480	468	476
Croatia	105	71	72	69	73	61	67	56	65	61
Italy	621	589	576	551	578	602	570	600	612	534
Cyprus	13	13	10	8	10	16	14	15	8	-
Latvia	79	60	62	70	71	63	55	51	50	40
Lithuania	-	-	-	96	109	81	-	-	-	-
Luxembourg	1	6	6	5	3	7	8	4	3	2
Hungary	192	124	156	147	152	149	152	170	165	144
Malta	-	-	-	-	-	5	8	7	2	-
Netherlands	62	65	64	51	50	60	44	64	50	49
Austria	98	87	81	82	71	84	73	73	47	69
Poland	1 236	1 408	1 157	1 140	1 116	915	868	873	803	793
Portugal	195	199	159	144	145	146	123	130	163	-
Romania	868	747	728	726	697	649	717	733	690	729
Slovenia	26	21	19	20	14	16	22	10	13	15
Slovakia	126	-	-	-	-	-	80	55	72	80
Finland	35	41	29	34	36	32	29	27	25	15
Sweden	31	53	50	42	52	28	42	37	34	27
European Union	5 952	5 986	5 441	5 308	5 246	4 998	4 966	4 870	4 763	4 668
Iceland	2	4	2	1	0	1	2	0	0	1
Norway	24	16	22	18	18	12	15	11	13	13
Switzerland	75	69	75	69	43	58	50	47	43	37

When it comes to the number of pedestrian fatalities by age group, statistics of 2019 showed that the most vulnerable age group in Greece was that of the ages >65 years, and the second group with a high number of fatalities is one of 25-49 years. The group with the lowest fatalities was the age group 15-17 years (table 2.3)

Table 2.3: Number of pedestrian fatalities by age group and by country for the last available year | Mobility and transport (europa.eu)

Country	Year	Unknown	<15	15 - 17	18 - 24	25 - 49	50 - 64	65+	Total
Belgium	2019	4	6	1	7	26	13	35	92
Bulgaria	2019	2	7	2	1	28	33	81	154
Czechia	2019	1	3	3	9	34	17	44	111
Denmark	2019	0	0	0	3	7	3	17	30
Germany	2019	0	22	6	27	68	63	235	421
Estonia	2019	0	1	0	0	2	2	6	11
Ireland	2016	0	2	1	1	11	6	14	35
Greece	2019	8	6	1	5	35	24	66	145
Spain	2019	5	12	2	12	72	61	217	381
France	2019	0	11	10	32	102	74	247	476
Croatia	2019	2	6	0	0	13	11	29	61
Italy	2019	5	8	3	18	90	94	316	534
Cyprus	2018	-	0	-	0	1	2	5	8
Latvia	2019	3	1	0	0	15	14	7	40
Lithuania	2015	1	1	1	5	20	19	34	81
Luxembourg	2019	-	0	0	1	1	0	0	2
Hungary	2019	1	4	0	9	31	38	61	144
Malta	2018	-	0	0	1	0	0	1	2
Netherlands	2019	1	3	0	3	8	5	29	49
Austria	2019	0	6	0	5	9	9	40	69
Poland	2019	8	15	9	41	192	230	298	793
Portugal	2018	-	2	3	6	20	43	89	163
Romania	2019	8	33	9	6	153	220	300	729
Slovenia	2019	-	0	1	0	3	2	9	15
Slovakia	2019	1	2	1	3	16	28	29	80
Finland	2019	0	0	0	1	6	2	6	15
Sweden	2019	0	2	0	1	8	4	12	27
European Union	2019	50	153	53	197	971	1 017	2 227	4 668
Iceland	2019	0	0	0	0	0	0	1	1
Norway	2019	0	0	0	0	2	2	9	13
Switzerland	2019	0	2	1	1	7	2	24	37

Moreover, 13 European countries have been collecting injury data from the accidents and organising them in the EU Injury Database. The reports can provide information on the casualties attending hospital, the length of stay there, the nature and type of body part injured and probably the long-term consequences of injuries.

Figure 2.10 shows that 45% of the pedestrians that were involved in accidents needed medical health and hospitalisation, while figure 2.11 shows that the average number of hospitalisation days has an average of ten days for pedestrians and eight days overall. These facts confirm the vulnerability of these road users toward the other groups.

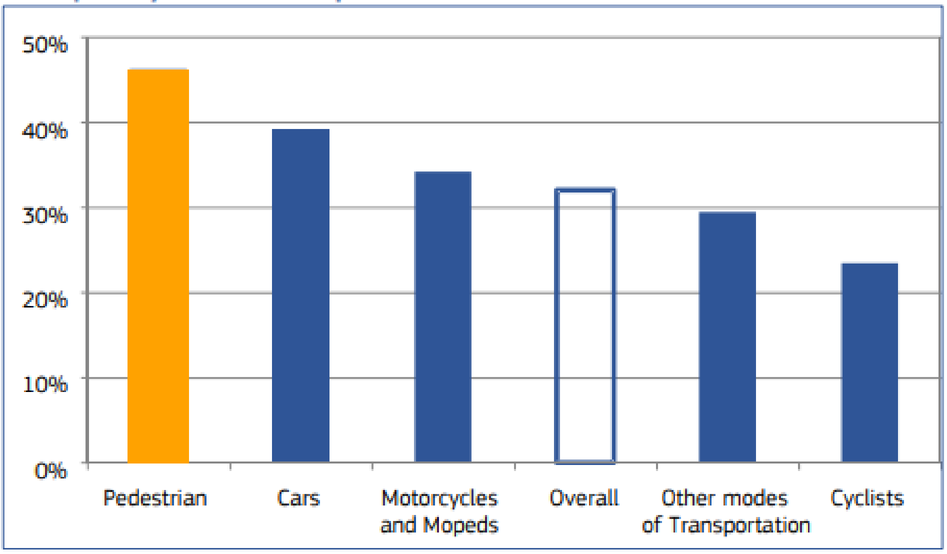


Figure 2.10: Percentage of non-fatal accidents that were admitted to hospital by transport type

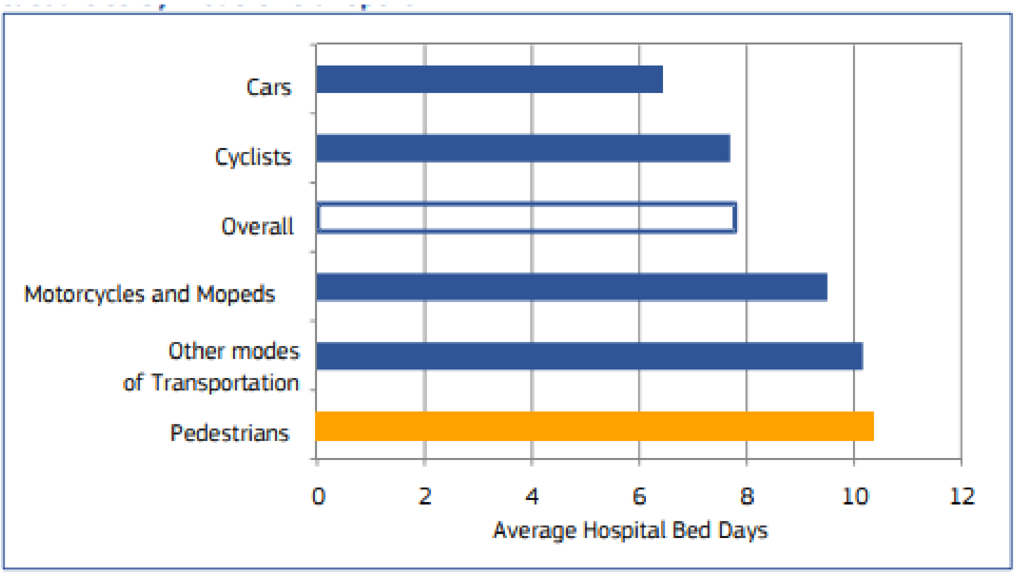


Figure 2.11: Average length of hospitalization of non-fatal road accidents by type of transport

Many studies have been conducted to analyse pedestrian accidents in particular related with the network characteristic, and some of them, like Schuurman et al. (2009), tried to connect them with the built environment. Specifically, the study of Schuurman et al. (2009) analysed combined data of pedestrian accidents in Vancouver during the period 2000-2005 and 2001-2006, from each data source, respectively. They found the locations of the hotspots, which were concentrated mainly in the city centre and downtown streets. Among 32 locations, 21 of them were found to be near bars, and 11 of them had high alcohol establishment density. They concluded that countermeasures were absent in most of the hotspots. Additionally, the risk of pedestrian injury was highly associated with bars' presence. Finally, proposes about possible locations for new signalised pedestrian crosswalks were made.

Another study was conducted by Benedek et al. (2015) in a Romanian city to not only identify the hotspots of the road network but also link them to the social background of road traffic crash occurrence. Kernel Density estimation was used to determine the hotspot locations, while the street segments were divided into four categories ranking the road hazard from low to high. From the pedestrians' perspective, the study reflected a different conclusion, as the most vulnerable group with higher crash involvement was women of ages 11-25.

Another interesting study is that of Blazquez and Celis (2012) in Santiago, Chile. They analyse data of child pedestrian crashes, which is a topic that not many studies have been able to analyse. Their Spatio-temporal analysis includes data during the period 2000-2008 and identifies seven critical areas with high risk for child pedestrians. The methods used were those of Kernel density and Moran's I index. A positive spatial autocorrelation was found on factors like time of day, straight road sections and intersections and missing traffic signs, whereas, for crashes related to age attribute, the pattern was found to be random

2.3.3. Pedestrians risk management measures

In order to prevent pedestrian accidents, cities and local authorities are continually taking different measures and finding solutions not only for the improvement of the traffic network but also for the built environment to be more pedestrian-friendly. Generally, deaths and accidents that involve pedestrians may be reduced by taking measures like:

√ Reducing speed limits in certain areas

√ Taking caution of street lighting

√ Wearing bright reflective clothes

√ Planning for more uninterrupted footpaths

√ Designing crash-friendly car fronts for minimising injuries.

Road architecture can also have a huge impact on the limitation of collisions. Figures 2.12 and 2.13 display changes in the environment that aim in limiting the vehicles' speed and lead to more comfortable walking zones.

Figure 2.12: Road architecture solutions for more pedestrian-friendly cities

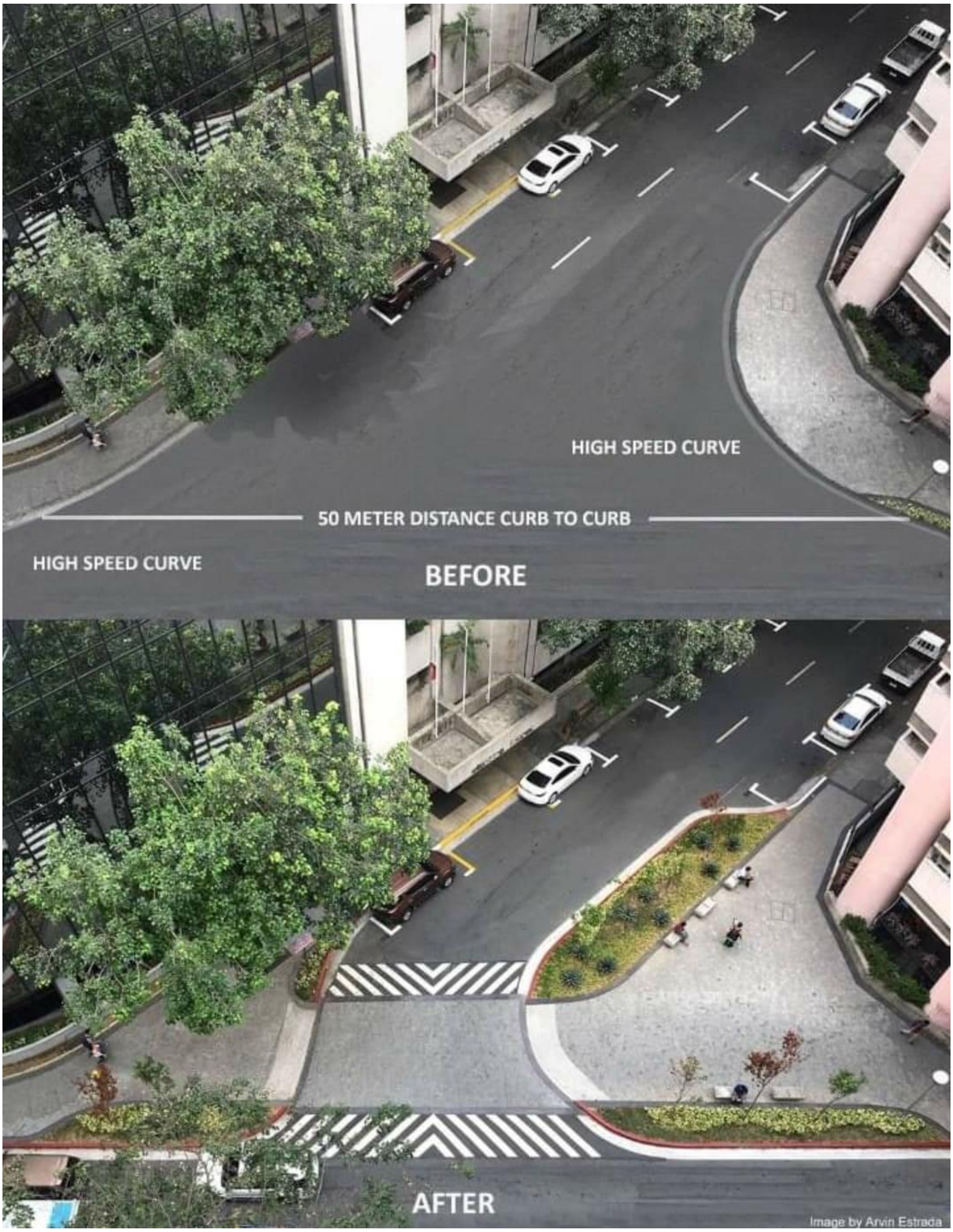


Figure 2.13: Changes in road architecture and design to pedestrian-friendly solutions

In addition, countries have been taking active measures through programs and projects in favour of pedestrians. The European Commission, in particular, has continuously supported new developments in road safety through subsequent framework projects and other safety initiatives. Some of them involve long-lasting projects, which are mentioned below:

• Aprosys

This Integrated Project on Advanced Protection Systems (APROSYS) aimed to improve passive safety for all European road users in all relevant accident types and accident severities, by introducing and developing new technologies. The project focused on scientific and technological development in the field of passive safety (crash safety), which concerns in particular human biomechanics, vehicle and infrastructure crashworthiness and occupant and road user protection systems. More specifically, the project aimed at introducing

- ✓ New mathematical models of the human body,
- ✓ New knowledge and tools for intelligent safety systems,
- ✓ Enhancement of virtual testing technology,
- ✓ New test methods,
- ✓ Advanced protection systems for injury reduction in most relevant accident types.

About the protection of the vulnerable road users, the APROSIS aimed to develop evaluation methods and advanced protection systems for cars, multi-purpose vehicles and sport utility vehicles, as well as to introduce test methods for vehicle front end to assess pedestrians, developing vehicle-based pedestrian and pedal cyclist safety technologies and material models for laminated materials.

• Watch over

This project started in January 2006 and successfully ended in December 2008. It was co-funded by the European Commission Information Society Technologies to design and develop a cooperative system to prevent accidents involving vulnerable road users (pedestrians, cyclists and motorcyclists) in urban and extra-urban areas. It was based on a communication system between the vehicles' onboard module and the vulnerable road users that were equipped with the Watch-Over module. The relative position of the user vs the drivers is real-time detected while the appropriate information to the driver is given only in perilous situations. Furthermore, feedbacks are given to the road user with visual or acoustic warnings (HMI).

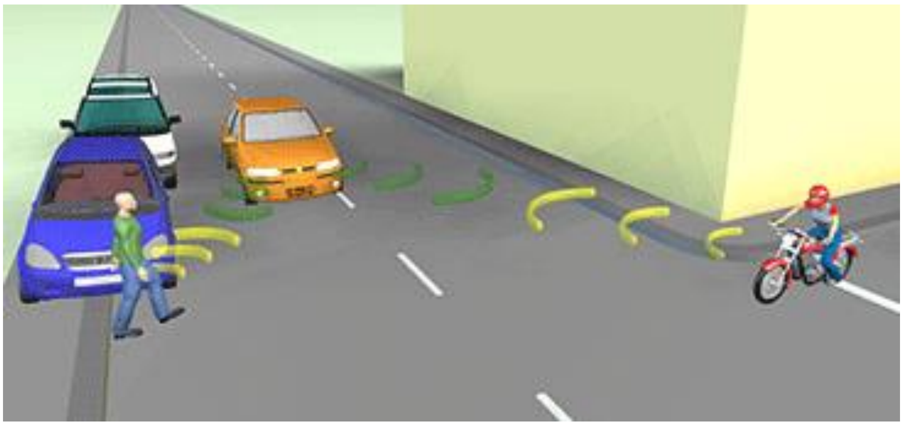


Figure 2.14: WATCH-OVER: Vehicle-to-Vulnerable road user cooperative communication and sensing technologies to improve transport safety (watchover-eu.org)

• VOICE

VOICE is an activity of ETSC whose main purpose is the protection of vulnerable road users (pedestrians, cyclists) by raising awareness of their needs. The aim is to acknowledge the responsibility and to implement drastic measures that are necessary for the protection of these users.

Finally, within the context of smart management, cities around the world have begun to implement different ways, like Light Detection and Ranging (LiDAR), to monitor traffic as an action to protect pedestrians and cyclists, especially during night hours. LiDAR sensors can be installed in key locations, like intersections and particular road locations, to collect traffic data autonomously. These data, when processed, can provide useful information about pedestrian movement and traffic density, identify speeding vehicles and then compare by the time of day, day of the week to identify patterns and make predictions for the future. All these conclusions can help urban and transportation planning to improve policies and traffic safety (Becker, 2021).

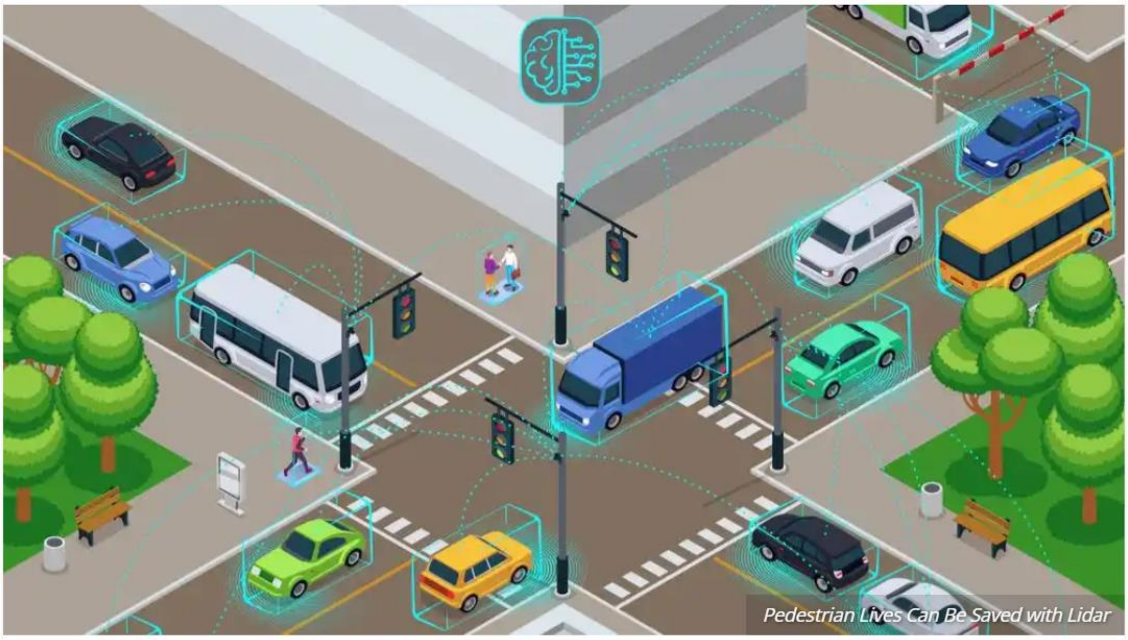


Figure 2.15: LiDAR technology in help of traffic management (www.lidarnews.com)

3. METHODOLOGY

3.1. Introduction

This chapter refers to the methodology followed for analysing the factors of the urban morphology that affect pedestrian safety and, therefore, lead to accidents. Methods presented were followed for the segmentation of the data collected. Methodology constitutes a valuable scientific tool, which determines the given approach to the examination of the phenomena. The current thesis aims to analyse the Spatio-temporal data of the pedestrian accidents in the city of Athens and correlate them with the urban morphology and land use through GIS network analysis tools. The analysis requires an in-depth understanding of the case area to determine the factors that might affect it.

This chapter outlines the specific characteristics of the case area and refers to the parts of the methodology used along with the variables needed for the analysis. In addition, there is a brief description of the tools, methods and techniques used during the network analysis. Finally, data collection and use are mentioned for a better understanding of the sample.

3.2. The case area

Figure 3.1: An aerial view of Athens, as the sun sets behind the city's most famous ancient landmark, the Acropolis(Source: https://www.dailymail.co.uk)

Athens is the capital and the largest city of Greece. According to the European Statistical System (ESS) – Eurostat, Athens is the 6th most overpopulated capital of the European Union, with a population of nearly 3.000.000 citizens in Greater Athens and an area of 400 km^2. The Athenian road network consists of major highways, boulevards, paved roads and the demand amounts to 8.900.000 routes on a typical daily basis. Cars are the main means of transport, and the number of private cars in Athens reaches approximately 3.000.000 vehicles.

The city of Athens was chosen as the case area since it is the biggest and most populated city in Greece. Its population density compared with the land area makes it quite interesting to examine. Moreover, the road network of Athens is quite complicated, as it consists of many central arteries running through the city and connecting it with the surrounding areas. The most common problems that occur due to this fact are traffic jams, road accidents, reduced space of car parks and difficulties in using other eco-friendly means of transport, like cycling and walking. These issues lead to air and noise pollution, high energy usage, high economic costs and life degradation. The reduced movement space for pedestrians raises safety issues during their interactions with the vehicles using the same network.

The city of Athens dominates the Attica region and is located at the very centre of it (figure 3.2).

Figure 3.2: The city of Athens in ArcMap

The population of the Municipality of Athens, which constitutes a small administrative unit of the city, was recorded as 664,046 citizens by the 2011 census, while the land area of the city is 38.96 km^2. It is divided into seven local communities, which include the historic centre of the city and the surrounding neighbourhoods (figure 3.3).

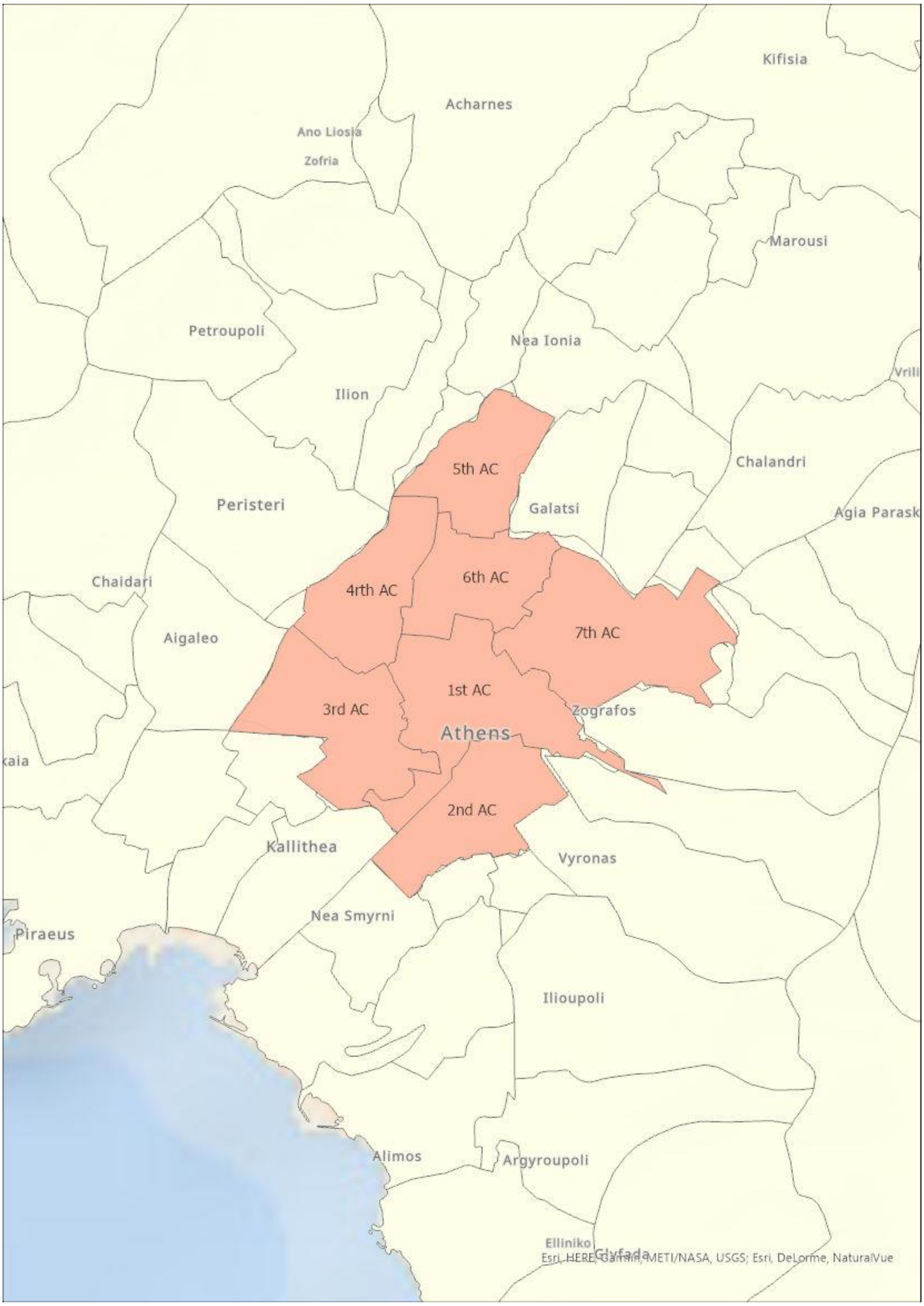


Figure 3.3: Athens city local communities

Table 3.1 shows the areas that are located in each of the seven local communities and their population, as found during the census of 2011.

Table 3.1: Athens city communities

Communities	Areas	Population
1st AC-Central area	Syntagma, Omonia, Monastiraki, Plaka, Kolonaki, Lykavittos, Exarcheia, Koukaki, Ilisia, Makrygianni	75.810
2nd AC-North East area	Pangrati, Zappeion, Mets, Kynosargous, Gouva, Neos Kosmos, Dourgouti	103.004
3rd AC-North West area	Asteroskopeio, Petralona, Thission, Rouf, Votanikos	46.508
4th AC-West area	Kolonos, Akadimia Platonos, Kolokynthou, Profitis Danaiil, Sepolia, Nirvana	85.629
5th AC-North West areas	Kato Patisia, Probona, Agios Eleftherios, Patisia, Rizoupoli	98.665
6th AC- North areas	Plateia Amerikis, Plateia Attiki, Kypseli, Nea Kypseli, Ano Kypseli	130.582
7th AC- North East	Nea Filothei, Ampelokipoi, Goudi, Kountouriotika, Erythros Stavros, Girokomeio, Polygono, Gkyzi	123.848

3.3. Analysis Techniques

As previously stated, it is important that before proceeding in the main analysis, the sample is understood in-depth and that the accidents are organised based on the categories that are to be examined. Therefore, the analysis consisted of three main parts:

- Statistical Analysis
- Spatial Analysis
- Network Analysis

3.3.1. Statistical Analysis

Statistical analysis is the science and study of the collection, organisation, analysis, interpretation, and presentation/visualisation of data. It is the first and very important step of the identification of the population used in the study. It can be defined as Descriptive and Inferential Statistics.

The first one outlines the population data characteristics in consideration to what is observed in the sample by describing it numerically or graphically. Categorical data can be described by frequency and percentage, while numerical descriptors, like standard deviation, are useful for continuous data types.

The second one uses patterns of the sample data to draw inferences, taking into consideration randomness. Inference can include interpolation or extrapolation of spatial data or time series.

For the purposes of this study, the statistical analysis took place in ArcGIS Pro and Excel. ArcGIS Pro offers the option of using the data attributes to create different types of charts, including line charts, bar charts, scatter plots, QQ plots, histograms etc. An ArcGIS Pro chart is defined by the chart class, which can also be used to define the chart title, axes and other properties. The chart class is a parent class for additional classes in the arcpy.charts modules.

Using both Excel and ArcGIS Pro charts, the data was studied and processed statistically and quantity in categories and was visualised and presented in tables and charts.

3.3.2. Spatial Analysis

The main aim of Spatial Analysis is to detect patterns of space and identify and model the interactions of these patterns to understand the representation of space and processes efficiently (Fischer, 2006).

Explanatory data analysis is used to determine patterns within a sample, outliers and trends. Techniques like these are effective for highlighting particular features and detecting relationships within the sample. As an extension of exploratory data analysis, exploratory spatial data analysis deals mostly with the aspects of space (Haining, 1990; Fischer 2006).

When referred to GIS, spatial analysis and transportation (GIS-T), Miller (1999) mentions the first one as a vehicle that disseminates spatial analysis tools to transportation researchers.

Spatial Analysis took place in GIS software. Due to licence restrictions, both ArcMap and ArcGIS Pro were used. More specifically, the techniques and tools used are described as follows.

- Spatial pattern

A spatial pattern is used to identify the spatial distribution of pedestrian accidents. The spatial pattern describes the way a group of variables is spatially arranged (Photis, 2009). However, the researcher should take into consideration the fact that the spatial patterns are identified in maps, which are statical spatiotemporal captures (Koutsopoulos, 2009). Furthermore, the area extension and boundaries, as well as the projection system, are to be considered during a spatial pattern analysis. The spatial pattern can be captured in three different types:

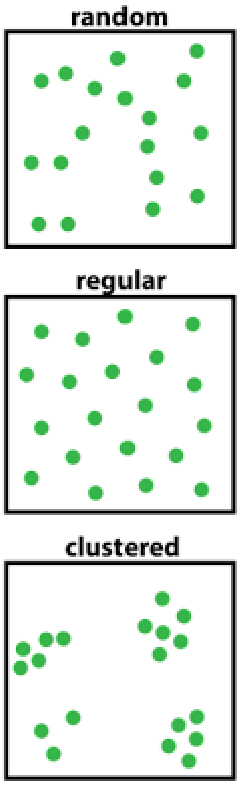


Figure 3.4: Basic types of spatial patterns

- ✓ Random pattern

  If a random pattern occurs, there is no meaning in analysing it further as it indicates that the probability of a variable's appearance in a random location is the same and the location of a variable is not related to the location of another variable of the same distribution.

- ✓ Regular pattern

  Regular patterns are usually spotted in competitive processes with the purpose of the variables to have a significant distance between them. This pattern indicates that the distribution's density of the variables is equal.

- ✓ Clustered pattern
  A clustered pattern appears when the variables exist close to one another, facilitating the transfer of properties.

One of the most commonly used methods for determining the spatial pattern is Nearest Neighbor Analysis, which focuses on the distance between the data points. It is possible to first calculate the expected mean centre from the nearest neighbour distances for a random pattern, while it has to be compared subsequently with the real-observed value of the distribution. The expected mean value of the distances between every point and its nearest in the case of the random pattern is calculated by the equation:

$$d_a = \frac{1}{2}\sqrt{\frac{N}{A}}$$

For N: the number of points and A: the case study area

The observed mean centre of the distances each point has from its neighbour is calculated using the equation:

$$d_{\Pi} = \sum_{i=1}^{N} \frac{d_i}{N}$$

For d_i: the distance of each point from its nearest

The spatial pattern is determined by the quotient $d\Pi \,/\, da$. This quotation's values can have a range from 0 to 2149 which stands for the regular pattern (Clark and Evans, 1954). In the case of a random pattern, the given value is 1 as the expected mean distance is equal to the observed value. However, the Nearest Neighbour Analysis shows the tendency of the phenomenon and does not determine the spatial pattern. It is very important to determine the exact boundaries of the study area which is highly correlated with the spatial pattern determination. Specifically, a certain point group that is located in a specific area with a random pattern, doesn't necessarily have the same pattern with a larger area that contains the previews one (Clark and Evans, 1954).

- Kernel density

Kernel Density Estimator was used to identify the denser areas, depending on the severity of the accidents. This method uses the density of near variables to calculate the characteristics of the area capturing the real essence of space; rather than focusing on specific areas, it identifies the characteristics of the whole neighbourhood (Porta et al., 2009)

- Mean Center

The mean centre, which is the main indicator of spatial centrality, was calculated for every group of accidents depending on the year they occurred and their severity. Every spatial point feature i has its coordinates x_i and y_i, which for the mean centre are described by the following equations. These functions calculate the coordinates of the centroid of all the points of the sample that have the same weight.

$$\bar{x} = \frac{\sum_i^n x_i}{n} \qquad , \qquad \bar{y} = \frac{\sum_i^n yi}{n}$$

In case the points, of which the mean centre is calculated, do not have the same weight then it is calculated by the following equations:

$$\bar{X} = \sum_{i=1}^{n} x\,ifi \quad , \quad \bar{Y} = \Sigma_{i=1}^{n} yifi, \quad fi = \frac{P_i}{\Sigma_{i=1}^{n} P_i} *$$

*f_i is the relative weight, and P_i is the i points' weight

If we use the mean centre as a number, described by its coordinates, it makes no significant sense. On the contrary, it is a very important indicator when it is graphically presented on a map along with other geographical distribution points. The mean centre is a location that represents a concentrated distribution on a map, providing important information to the researchers (Koutsopoulos, 2009). The mean centre is used to study the temporal changes of a factor and can be used as an indicator for the comparison of distributions of the same phenomenon for the same spatial unity. The locations of the mean centres at a specific time provide important spatial information about the area studied. In addition, it is possible that the same mean centre can result from two different geographical distributions (Photis, 2009). The mean centre does not change due to a shift or permutation of the coordinate system.

- Spatial Autocorrelation – Global Moran's I and Local Moran's I

Spatial autocorrelation defines the relation between the values of a single variable and is related to the geographical arrangement of the area where the variables are detected. It detects the data similarity in a specific area, the degree of the autocorrelation of the spatial phenomenon, the autocorrelation between the variables, the type and strength of the interdependence (Cliff, A. and Ord, J.K., 1981). Thus, spatial autocorrelation is an evaluation of the correlation of the variables, referred to their spatial location, while it assesses whether a spatial plan exists in case of the variables being interrelated (Photis, 2009).

Spatial autocorrelation affects data distribution as the values of a variable tend to have a more centralized distribution. In a positive autocorrelation, the similar variables are gathered together, while in a negative autocorrelation, the dissimilar variables are (Photis, 2009). In cases of positive autocorrelation the entities operate at the same intensity, while when a negative autocorrelation occurs, areas that interrupt the phenomenon can be identified, which can be superior or lagged compared to the general area.

Many spatial autocorrelation indicators can be used depending on the research (Cliff and Ord, 1981; Goodchild, 1986; Chou, 1997). This study uses Global Moran's I for the categories of the pedestrian accidents with a yearly weight, to identify the spatial pattern through the years that the accidents occurred, and determine whether the pattern in the accidents' locations is random, regular or clustered.

Global Moran's I measures the correlation between adjacent observations in a spatial arrangement. Global Moran's I indicator is calculated as the quotient of spatial covariance with the total variation and it can take values from -1 to 1 (Moran, 1950). Positive values stand for positive spatial autocorrelation, while the opposite stands for negative values. The zero value indicates that the autocorrelation is neither positive, nor negative, and the pattern is random. Moran's I refers to all the study areas. During 90's it was mentioned that a catholic indicator consists of local autocorrelations (Anselin, 1993; Anselin, 1995). Thus, it is important to use the local indicators in order to identify the specific concentration areas and their sizes. Local Moran's I, which is a local autocorrelation indicator, is described by the following equation (Anselin, 1995):

$$I_i = \frac{x_i - \bar{x}}{Si^2} \Sigma_{j=}^{n} 1 \neq wi, j(x_i - \bar{x})*$$

*x_i: descriptive feature of entity i

$\bar{x}: the\ mean\ value$

wi,j: the spatial weight between i and j entities

n: the number of entities

and S_i is determined by the following equation:

$$S_i^2 = \frac{\sum_{j=1 \cdot j \neq i}^{n} w_{ij}}{n-1} - \bar{x}2$$

Local Moran’s I indicator is a local autocorrelation index and has been widely used in the geographical analysis for finding the areas of variables’ concentration and their categorization in regular or clustered (Knight et al., 2018). The positive value of I shows that the entity is surrounded by other entities with similar values, meaning that the entity is part of a cluster. The negative value of I, on the other hand, shows that the entity is surrounded by entities with dissimilar values, and the entity is considered a spatial outlier. Local Moran’s I can be interpreted through the values of Z-score or p-value, which can indicate a high-value cluster (HH), low value (LL), and spatial outliers of high values surrounded by low ones (HL) and the opposite (LH).

In the case of the pedestrian accidents, Local Moran’s I can spot the locations with the highest values through time, indicating that in those locations accidents have currently occurred. Locations with the lowest values can spot the accidents that have occurred many years ago, and the spatial outliers indicate that the locations are hotspots for often accidents.

3.3.3. Network Analysis

During recent years Geographic Information Systems (GIS) and Network Analysis, have had a rapid development and use due to their scientific and methodological advances. The main purpose of GIS is to process geographic information, which is characterised by geographic location. Longley et al. (2001) mention that location is the most important and valuable asset of GIS, offering the ability to map compositions, and link different kinds of data that refer to the same space.

Network Analysis is part of GIS-T, which refers to geographic information science and systems with regards to transportation problems (Fischer, 2006). GIS-T requires new data structures than those of standard GIS, in order to represent the complexity of transportation networks effectively; thus, they perform different network algorithms.

A network can be considered as pure when it is characterised by its topology and connectivity or as flow when it is described by its topology and flow characteristics. Bell and Iida (1997) refer to the transportation network as a flow network consisting of vehicles, people movement and goods (Fischer, 2006).

The transportation network is usually represented by nodes and links, which represent respectively points of space, as well as possible time and pieces of transport infrastructure. Links can be undirected or directed towards the movement.

3.3.4. Geographically Weighted Regression

Regression Analysis is a statistical process that is used for the estimation of the correlation between a dependent variable with one or more independent variables. It is especially useful as it connects the changes of the dependent variable by changing one of the independent variables, while the rest of them remain constant. Linear Regression is the simplest case of the least-squares method where there is the dependent variable Xi and only one independent variable Yi. Geographically Weighted Regression (GWR) is used in spatial analysis, allowing the examination of the local fluctuations in spatial processes. It was firstly introduced by Fotheringham, Charlton and Brunsdon in 1996 (Andrikopoulou, 2019).

For the purpose of this study, Geographically Weighted Regression was used with pedestrian accidents selected as the dependent variable and the independent variables those of the categories of the points of interest. It is calculated with the definition of a circle around each remark of the dependent variable and the regression model is calculated from the remarks found inside the circle. The radius of the circle was chosen as the minimum walking distance.

3.4. Data collection methodology

Data collection is the most critical part of every research as it determines the quality and defines the results of the project. The data must be collected from accurate sources, that ideally also provide metadata to ensure quality and reduce errors. It is also one of the most challenging parts, as, although the amount of the available data is continually growing, it is not always possible to collect them either due to privacy restrictions or due to the fact that they are not free.

In this case, the collection was based on data available from competent bodies, which were processed and organised in specific datasets to consist of a proper database for the analysis. More specifically, the data was collected from the Hellenic Statistical Authority, which is responsible for the accidents' data collection and organisation of the digital records in Greece. The purposes and uses of the data may vary due to the differences in the services that might be using them. Therefore, the way they are organised and stored might not be appropriate for every kind of analysis. The spatial analysis also requires that the data are correctly stored in certain databases that can be analysed properly.

The database collected for the purpose of this thesis was previously used for analysis and therefore had already been processed through the process of Geocoding (Liogka 2019). This process uses the addresses of the locations where the accidents occurred and corresponds them to their exact coordinates. Errors might occur during Geocoding as it is completely automated. Therefore, some points might require manual corrections. The database available required the correction of approximately 15 points (figure 3.4).

More specifically, the dataset contains 1328 pedestrian accidents that occurred in the city of Athens during the years 2008-2017. The Hellenic Statistical Authority collects these data from the Hellenic Traffic Police, digitises and organises them in geodatabases. This is the basic source for collecting accident data in Greece as the Traffic Police is the only Authority to collect information when an accident takes place. The research about road accidents takes place every month and reviews the number of accidents that occurred in every municipality by organizing the accidents based on their severity and type (e.g. pedestrians, drivers, etc.). Broader research takes place every year, as well. Data collection and organisation is also done monthly. The basic factors registered are the accident location (address), road type, road condition, involved person identification and information. Accident data are released ten months after their collection.

Figure 3.4 shows the pedestrian accidents, as they were organised in a personal geodatabase for use in the ArcGIS software. As shown, the database contains information about the exact address where the accident took place, the year when they occurred, the severity, the number of persons involved and the mode, which in this study consists only of pedestrians. The severity of the accidents takes three different values: slight, serious, fatal.

Field: Add Calculate **Selection:** Select By Attributes Zoom To Switch Clear Delete Copy

Shape *	OBJECT	Year_	Address	Number_	City	FullAddres	lon	lat	Casualty	Mode	Persons
Point	3	2008	ΑΓΙΑΣ ΓΛΥΚΕΡΙΑΣ	22	ΑΘΗΝΑ	ΑΓΙΑΣ ΓΛΥΚΕΡΙΑΣ,22,Α...	37,98012	23,70827	Ελαφρά τραυματίας	Πεζός	1
Point	4	2008	ΑΓΙΑΣ ΛΑΥΡΑΣ	26	ΑΘΗΝΑ	ΑΓΙΑΣ ΛΑΥΡΑΣ,26,ΑΘ...	38,01826	23,73991	Ελαφρά τραυματίας	Πεζός	1
Point	5	2008	ΑΓΙΟΥ ΜΕΛΕΤΙΟΥ	36	ΑΘΗΝΑ	ΑΓΙΟΥ ΜΕΛΕΤΙΟΥ,36,Α...	37,99996	23,73573	Ελαφρά τραυματίας	Πεζός	1
Point	6	2008	ΑΓΙΑΣ ΠΑΡΑΣΚΕΥ...	21	ΑΘΗΝΑ	ΑΓΙΑΣ ΠΑΡΑΣΚΕΥΗΣ,2...	38,00802	23,73142	Ελαφρά τραυματίας	Πεζός	1
Point	7	2008	ΑΓΙΟΥ ΦΑΝΟΥΡΙΟΥ	32	ΑΘΗΝΑ	ΑΓΙΟΥ ΦΑΝΟΥΡΙΟΥ,32...	37,96538	23,751	Ελαφρά τραυματίας	Πεζός	1
Point	8	2008	ΑΓΙΑΣ ΘΕΚΛΑΣ	11	ΑΘΗΝΑ	ΑΓΙΑΣ ΘΕΚΛΑΣ,11,ΑΘ...	37,97752	23,72463	Ελαφρά τραυματίας	Πεζός	1
Point	9	2008	ΑΙΛΙΑΝΟΥ	10	ΑΘΗΝΑ	ΑΙΛΙΑΝΟΥ,10,ΑΘΗΝΑ	38,00938	23,73247	Ελαφρά τραυματίας	Πεζός	1
Point	10	2008	ΑΙΝΟΥ	16	ΑΘΗΝΑ	ΑΙΝΟΥ,16,ΑΘΗΝΑ	37,95703	23,7367	Νεκρός	Πεζός	1
Point	11	2008	ΑΙΟΛΟΥ	10	ΑΘΗΝΑ	ΑΙΟΛΟΥ,10,ΑΘΗΝΑ	37,97545	23,72743	Ελαφρά τραυματίας	Πεζός	1
Point	12	2008	ΑΙΣΩΠΟΥ	16	ΑΘΗΝΑ	ΑΙΣΩΠΟΥ,16,ΑΘΗΝΑ	37,9782	23,72373	Ελαφρά τραυματίας	Πεζός	1
Point	13	2008	ΑΙΣΧΙΝΟΥ	37	ΑΘΗΝΑ	ΑΙΣΧΙΝΟΥ,37,ΑΘΗΝΑ	37,97008	23,73084	Ελαφρά τραυματίας	Πεζός	1
Point	14	2008	ΑΚΑΔΗΜΙΑΣ	96	ΑΘΗΝΑ	ΑΚΑΔΗΜΙΑΣ,96,ΑΘΗΝΑ	37,98502	23,73172	Ελαφρά τραυματίας	Πεζός	1
Point	15	2008	ΑΚΟΜΙΝΑΤΟΥ	63	ΑΘΗΝΑ	ΑΚΟΜΙΝΑΤΟΥ,63,ΑΘ...	37,98902	23,72398	Ελαφρά τραυματίας	Πεζός	1
Point	16	2008	ΑΚΡΩΤΗΡΙΟΥ	3	ΑΘΗΝΑ	ΑΚΡΩΤΗΡΙΟΥ,3,ΑΘΗΝΑ	37,95102	23,72507	Ελαφρά τραυματίας	Πεζός	1

Figure 3.5: Pedestrian accidents' database

In addition to the accident locations, network data was collected, as well as background data of the city of Athens, for better visualisation and map compositions. Furthermore, three-point data sets were used for the network analysis and the correlation of the landuses to the accidents. The first one was the data set with the points of interest, comprised of different types of landuses. This was a large dataset downloaded from open street maps and obtained information on the locations and types of landuses that are spotted in the city of Athens. The other two datasets consisted of traffic and transportation data, which were considered to be important for this type of analysis, and they were analysed along with the points of interest (figure 3.5).

4. DATA ANALYSIS

This chapter includes the analysis methods used to process the available data as well as the conclusions of the analysis. First of all, the statistical analysis provides all the information needed to better understand the sample. In addition, space analysis methods were used to identify the locations of the high incidents' rates (hotspots), which were mapped using Geographic Information Systems (GIS). Network Analysis was used to determine the walkability from interest points, and identify the potential influence of certain land uses around the hotspots. Bivariate maps and Geographically Weighted Regression were used to specify the possible correlation. Finally, the analysis results were presented through maps and a dashboard.

4.1. Statistical Analysis - Sample Characteristics

As stated in the previous chapter, data collection was made by the Hellenic Statistical Authority. It consists of 1318 pedestrian accidents of different severity that took place in the city of Athens from 2008 to 2017. As shown in table 4.1, 1208 accidents were of slight severity, 80 were considered as serious, while 30 were fatal. The table also shows the accidents categorised by the number of persons involved as well as the number of accidents per year.

Table 4.1: Sample ID

Sample characteristics	Accidents
Occured	1318
Severity	
Slight	1208
Serious	80
Fatal	30
Persons Involved	
1	1241
2	68
3	7
4	2
No of accidents per Year	
2008	182
2009	182

2010	179
2011	173
2012	131
2013	98
2014	98
2015	97
2016	97
2017	81

Figure 4.1 shows the change in the number of accidents over the years, while figure 4.2 shows the change in percentages. During the years 2008 – 2012 the number of accidents continued to remain high. In 2012 there was a reduction in this number which continued until 2013. The percentage of pedestrian accidents fell below 8% and remained like this for the next years.

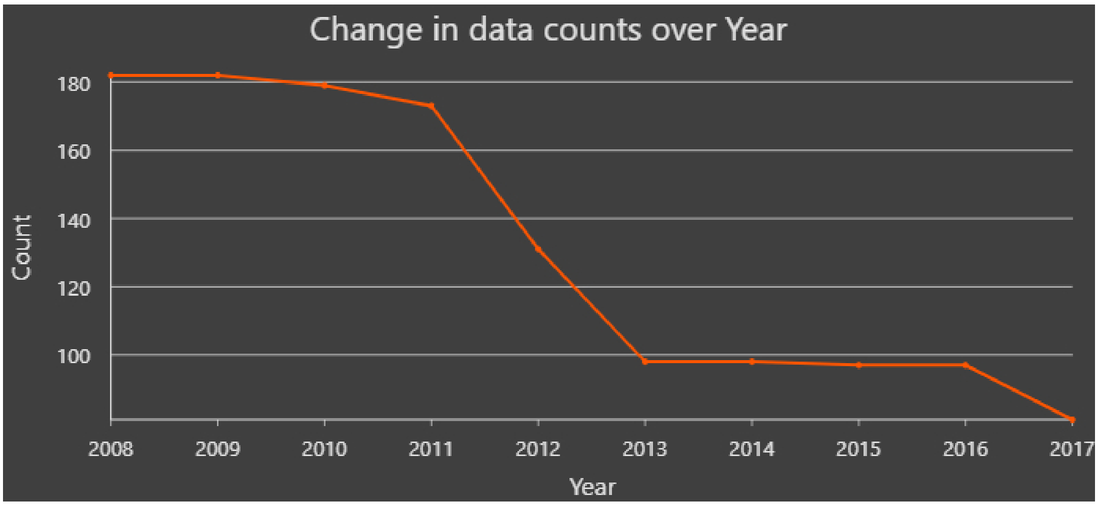


Figure 4.1: Change in data counts over Years (2008-2017)

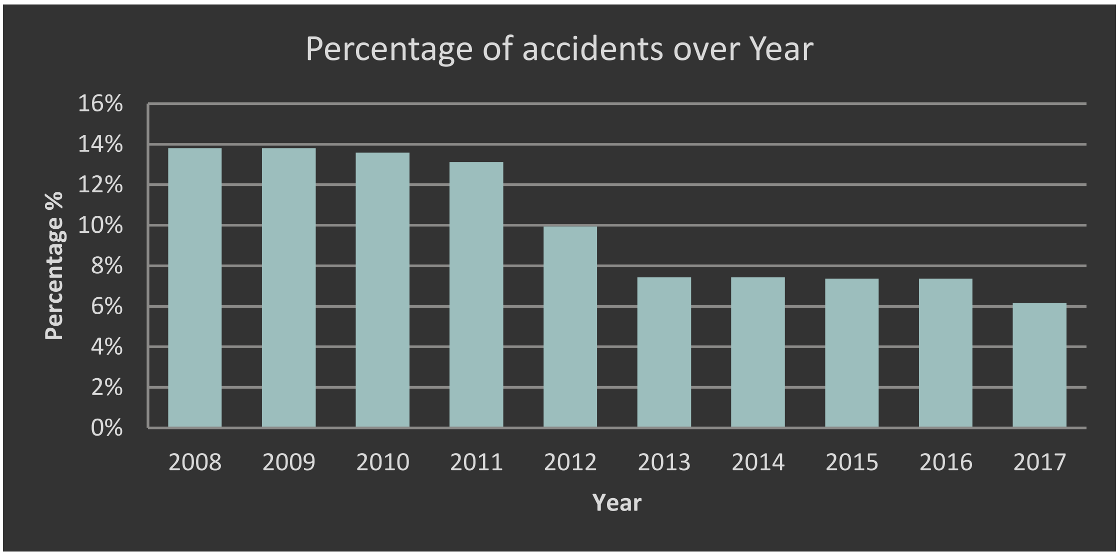


Figure 4.2: Change in percentage of accidents over Years 2008 - 2017

The decrease in road accidents came firstly as a result of the crisis in Greece, where the number of cars was reduced reportedly by more than 58% in 2011 (Hellenic Statistical Authority, 2011). In addition, after 2010, many efforts were made by the Public Authorities to decrease road fatalities. Efforts included infrastructure improvements, changes in legislation, education schemes and campaigns. As a result, Greece was recently awarded the 2021 Annual Road Safety Award of the European Transport Safety Council for achieving a reduction by 50% in road fatalities during the period 2010-2020 (ETSC, 2021).

Figures 4.3 and 4.4 show charts of the categorised severities over the years and their comparison each year, respectively. 2010 shows higher percentages in serious accidents than the other years, while fatalities were higher in 2013. Slightly injured accidents seem to follow the general pattern of the sample, which is considered normal as they represent the biggest percentage of it.

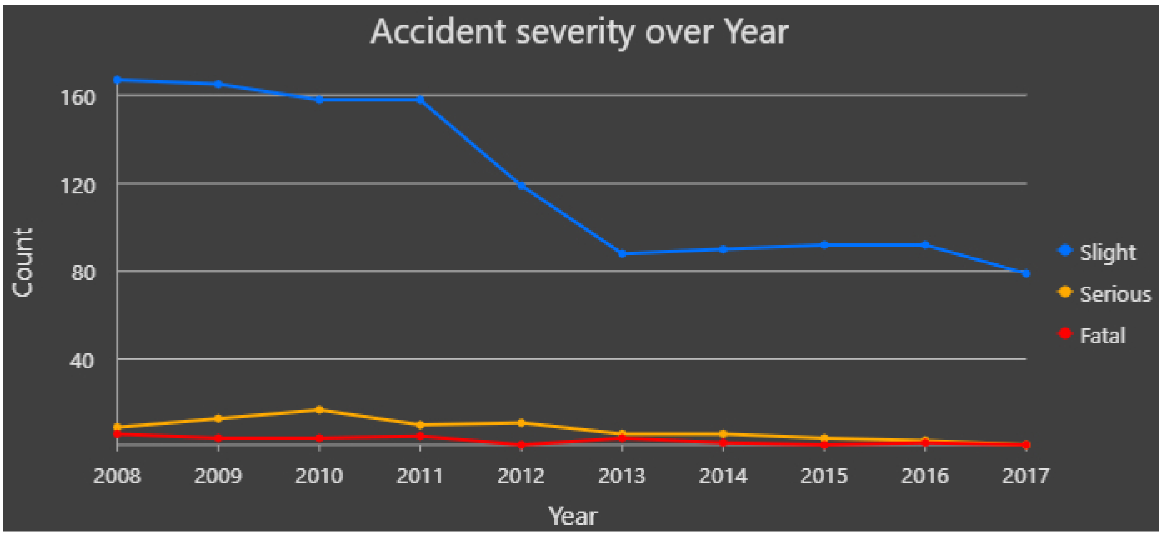


Figure 4.3: Accident severity through the years 2008-2017

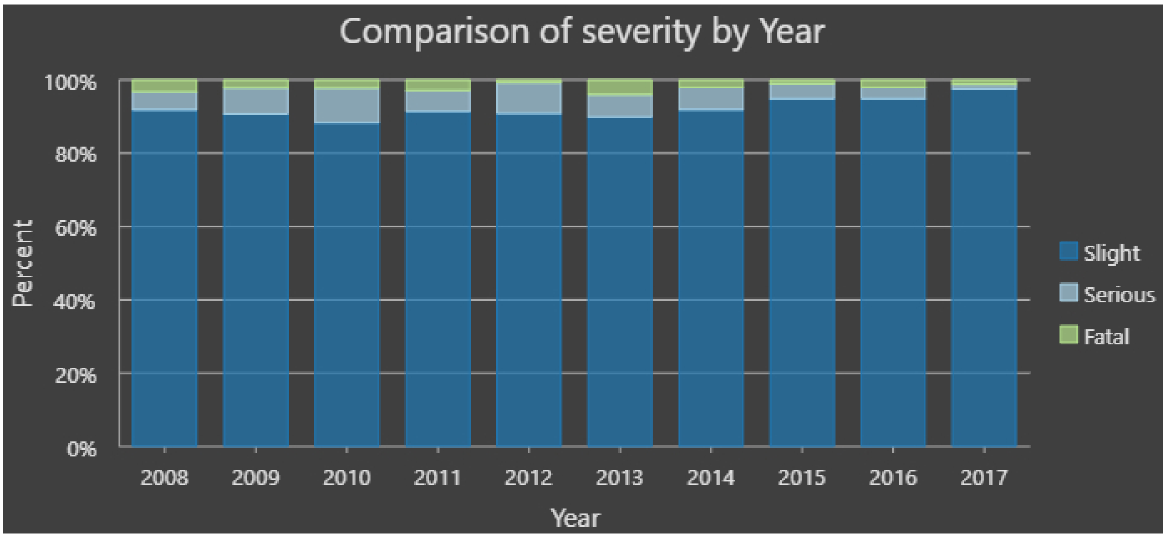


Figure 4.4: Stacked chart of accidents severity through the years 2008-2017

The last chart (figure 4.5) shows the persons involved in the accidents during the years. Accidents that involved four persons are spotted through the years 2008-2010. Accidents involving three persons have remained at the same levels since 2009. Furthermore, accidents, where two pedestrians were involved, ate spotted during all the available data, while they had two peaks in 2010 and 2016. Finally, the accidents with one pedestrian are high in percentage until 2011, fell below 90 in 2013 and below 80 in 2017.

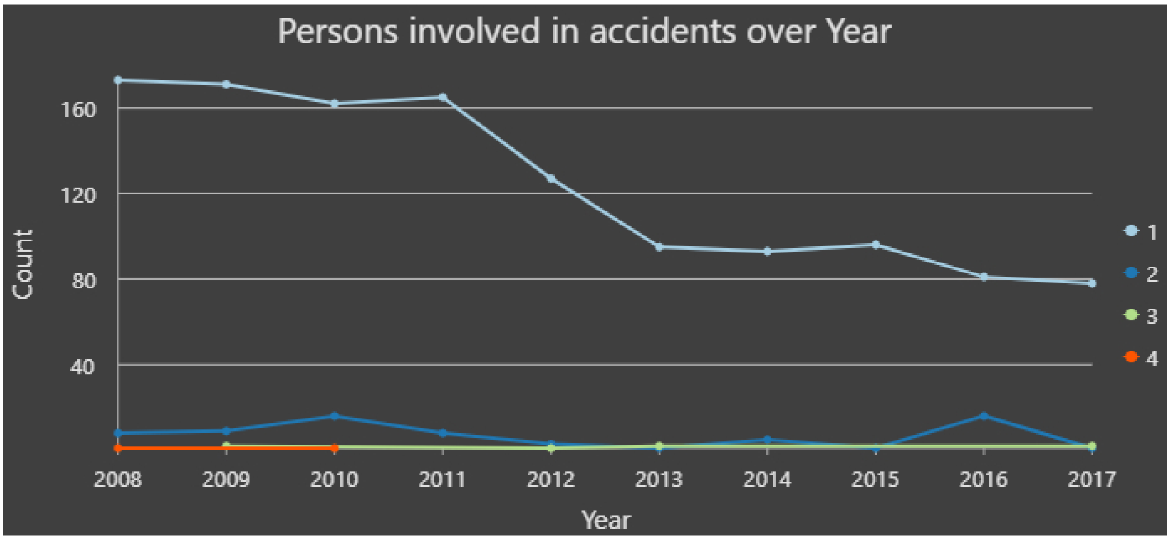


Figure 4.5: Chart or persons involved in each accident through the years 2008-2017

4.2. Spatial Analysis

Statistical analysis methods cannot always describe complex spatial relations between data. In this case, Geographic Information Systems and Spatial analysis are used to define the complex relations between different features (Photis, 2010). However, spatial analysis of pedestrian accidents cannot be determined as an isolated phenomenon without examining the road network and the urban environment.

During the analysis, the ArcGIS platform was used. ArcGIS Pro was used mostly for the visualisation and map processing, while ArcMap's use was necessary as well, primarily due to the restrictions of the software in trial and student use versions. Firstly, accident locations were categorised into groups based on the year they occurred (figure 4.6). As expected, most of the accidents are concentrated on the main roads of the city centre.

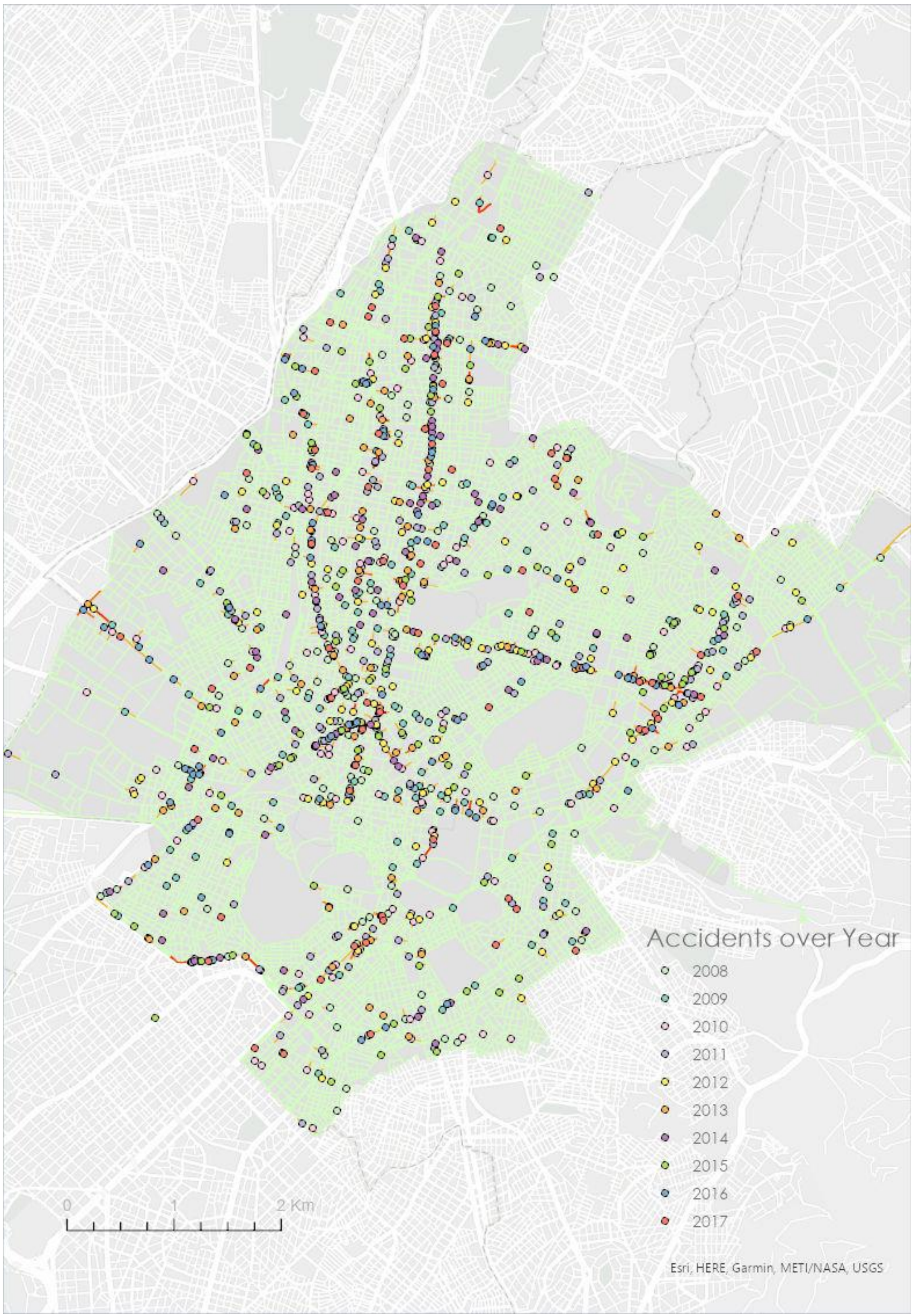


Figure 4.6: Pedestrians' accidents location over Years

In addition, they were also categorised based on their severity. To visualise the accidents by their severity throughout the years, the "small multiple" of maps in figure 4.7 were composed in ArcGIS Pro.

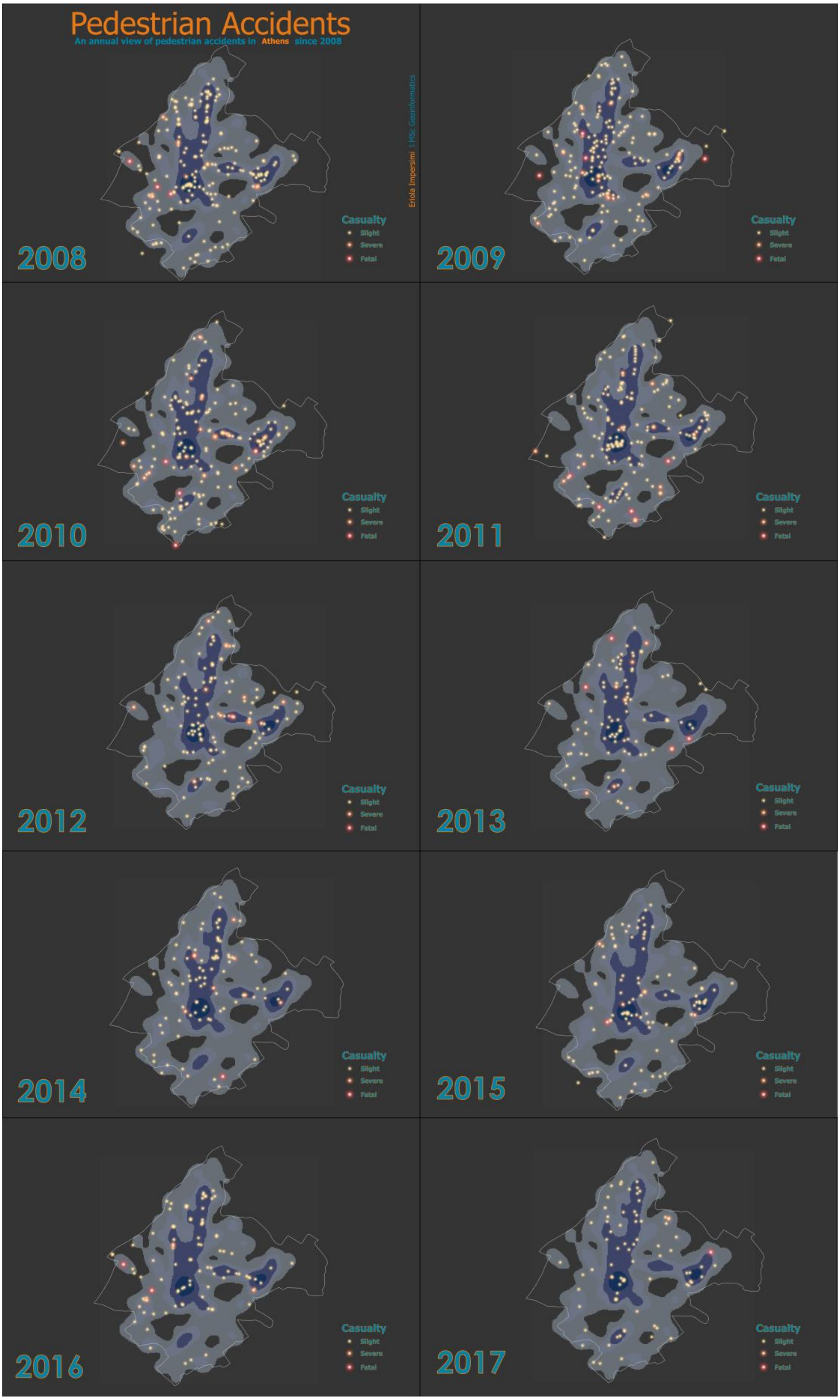


Figure 4.7: Small- multiples map of pedestrian accidents in Athens during the years 2008-2017

The map of figure 4.8 shows the concentration of the accidents in every local community normalised by the population of each of the seven communities. In order to compose this map, the layer of the local communities was enriched with the population number as stated at the National Statistics service from the census of 2011.

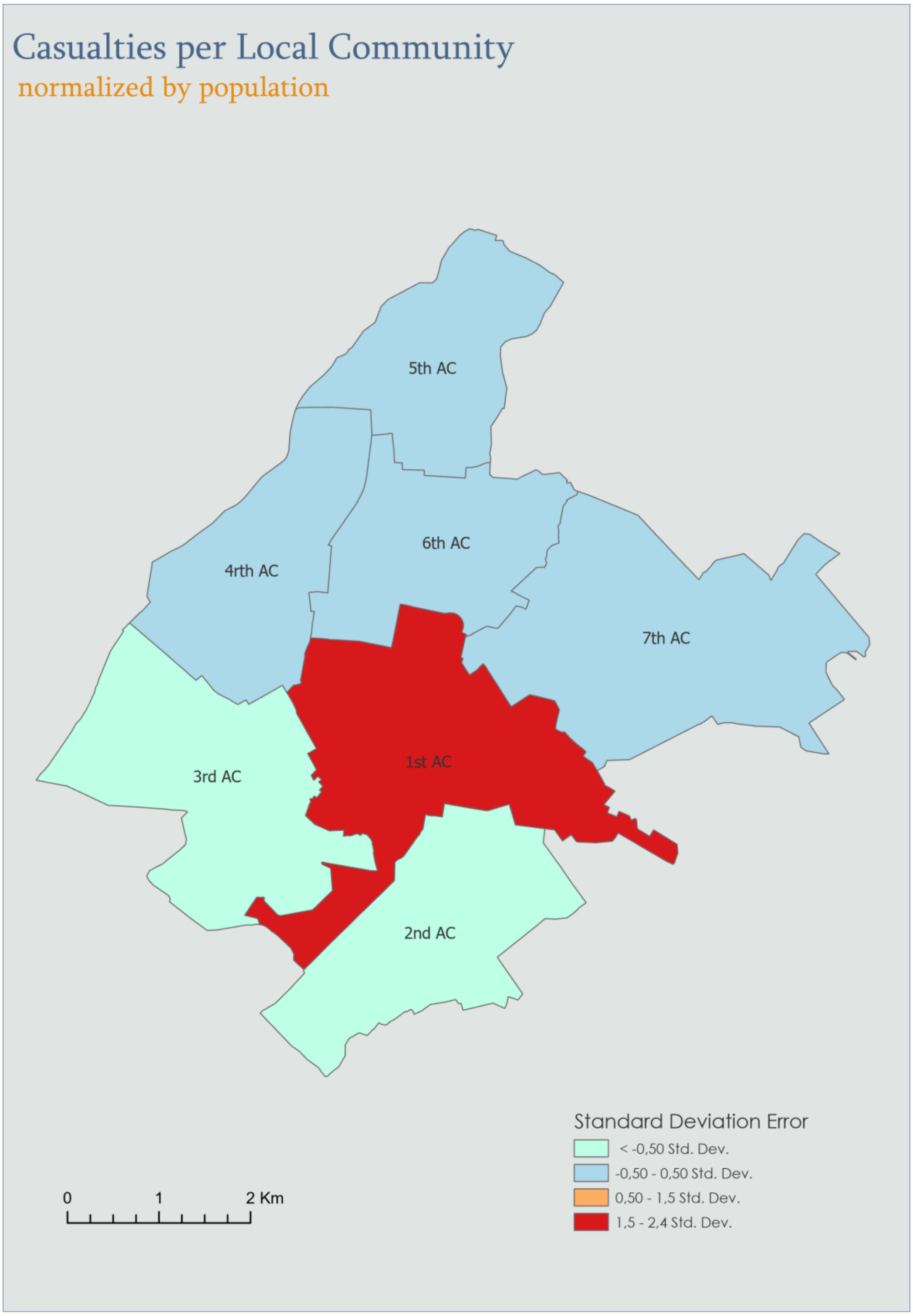


Figure 4.8: Standard deviation error of pedestrian accidents' density per population in the local communities of Athens

Moreover, the map of figure 4.9 shows the population density of each local community normalized by each area, respectively.

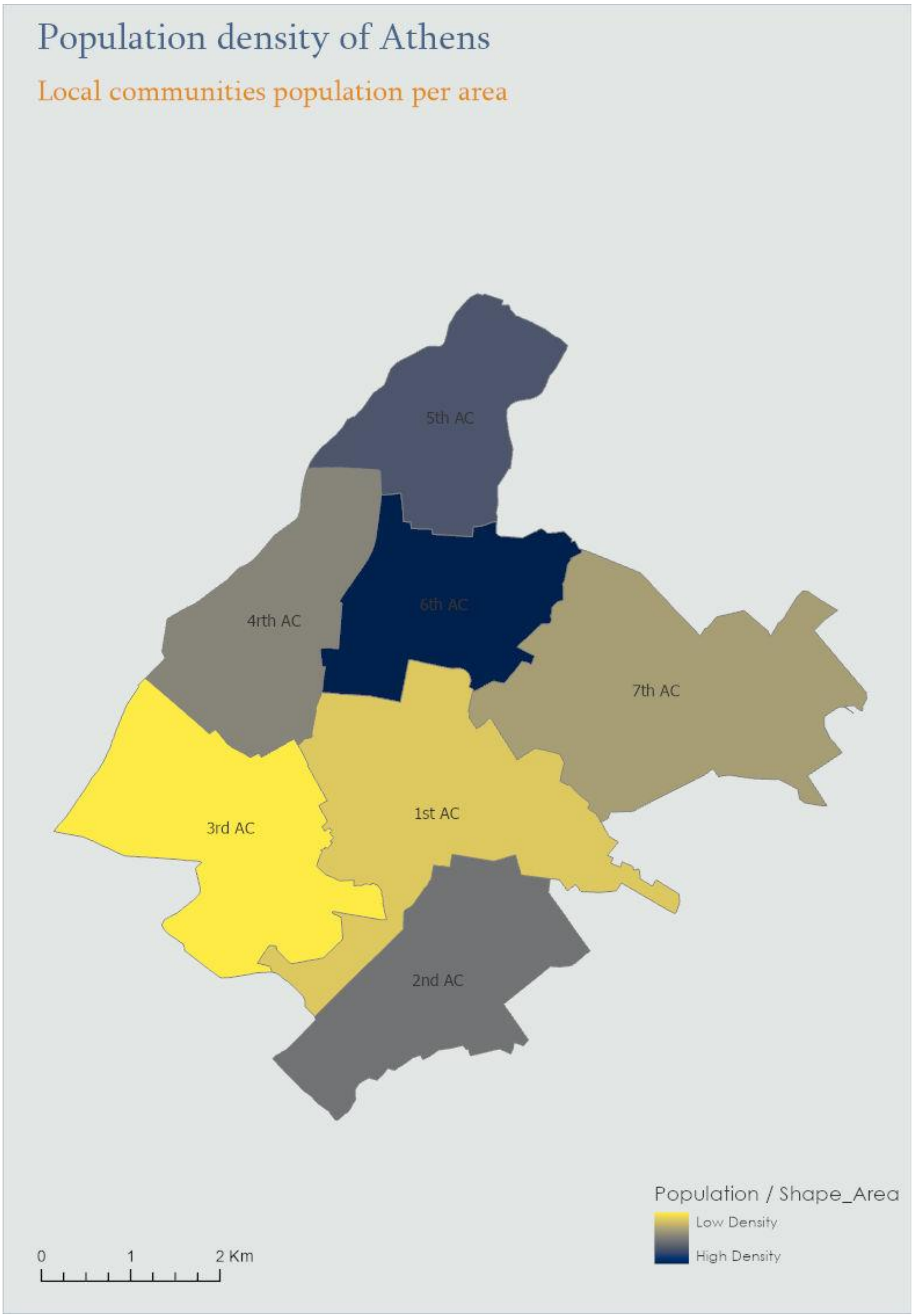


Figure 4.9: Population density per area of the local communities

As spotted, the 1st community has a higher density in accidents despite having a lower population number than the other. The results are better understood on the bivariate map of figure 4.10, which shows the concentration of pedestrian accidents vs the population per area. The 6th community appears to have the highest number of population and accidents, as well.

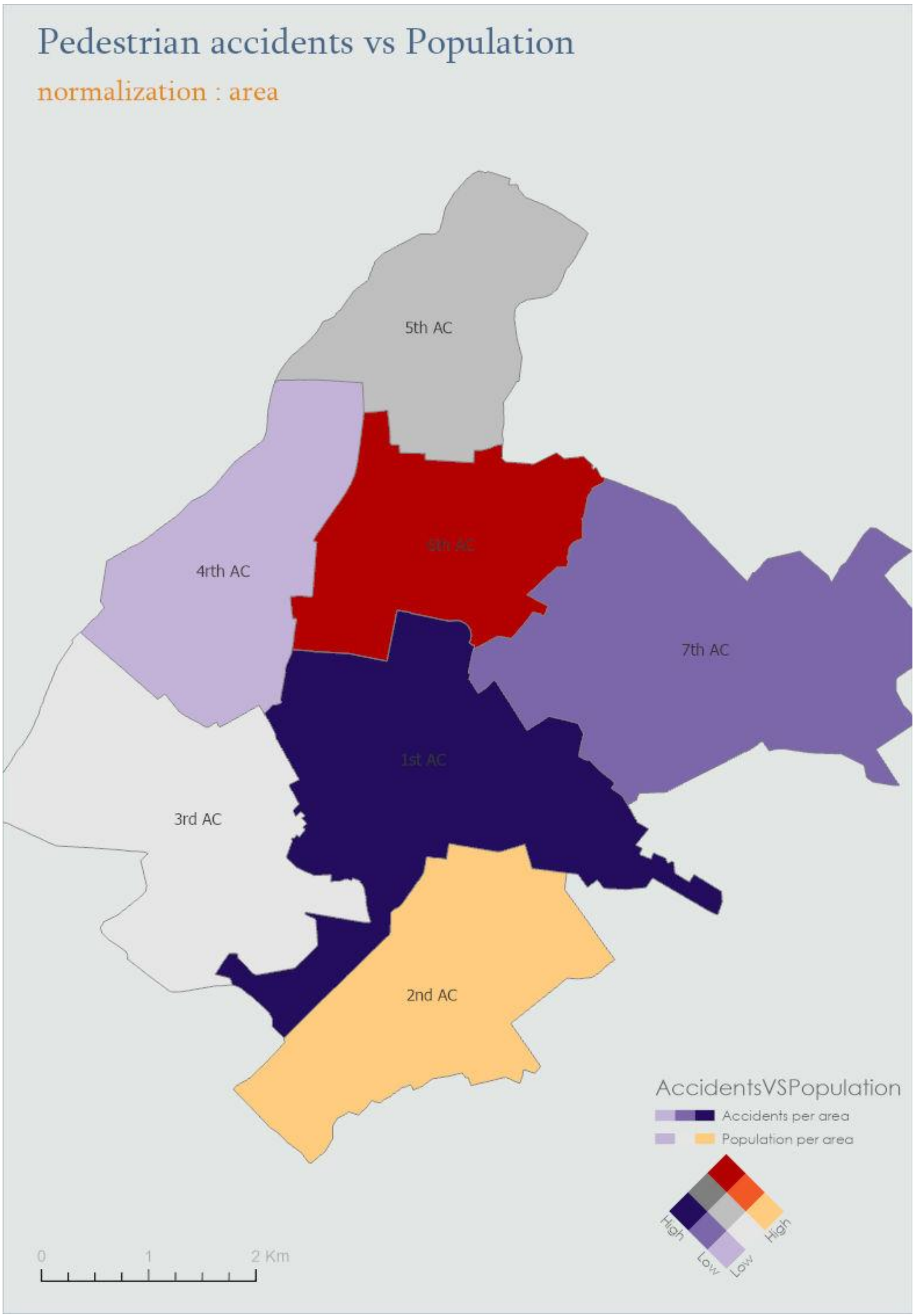


Figure 4.10: Bivariate map of pedestrian accidents and population density per local community

Space-time cube analysis was used to determine the pattern of the areas where more accidents took place. Space cube analysis takes into consideration the trends of accidents through the years and determines whether a hotspot is a new one or has been in a specific area through the years of the examination. Figure 4.11 shows the parameters used for this analysis. Through Geoprocessing, the Create Space Time Cube By Aggregating points

Tool was used. This tool requires a time field. It is necessary that during the data processing, the date is stored as such in a specific field of the attribute table and not as text; otherwise, the analysis will not run properly. The time step interval was set as one year due to the sample we had at our disposal. The aggregation shape type was set as a Hexagon grid, and the distance interval was set as 200 meters which is a normal average distance to take into consideration about pedestrian movement.

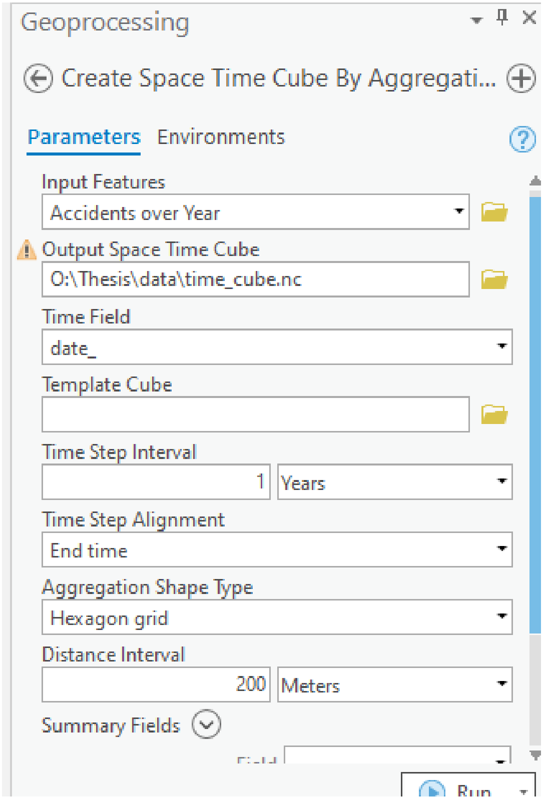


Figure 4.11: Space-Time Cube tool

At the end of the analysis, the software shows by default a message with detailed statistics about the analysis. It is pointed out that it has been a statistically significant decrease in accidents over time (figure 4.12).

```
Messages
Min Y                                      4199764,1455
Max X                                       481239,0952
Max Y                                      4209064,1455
Rows                                                 46
Columns                                              50
Total bins                                        23000

------------- Overall Data Trend - COUNT -------------
Trend direction                              Decreasing
Trend statistic                                 -3,7870
Trend p-value                                    0,0002
```

Figure 4.12: Space-Time Cube tool results

Figure 4.13 shows the patterns of pedestrian accidents in Athens as processed through the space-time cube.

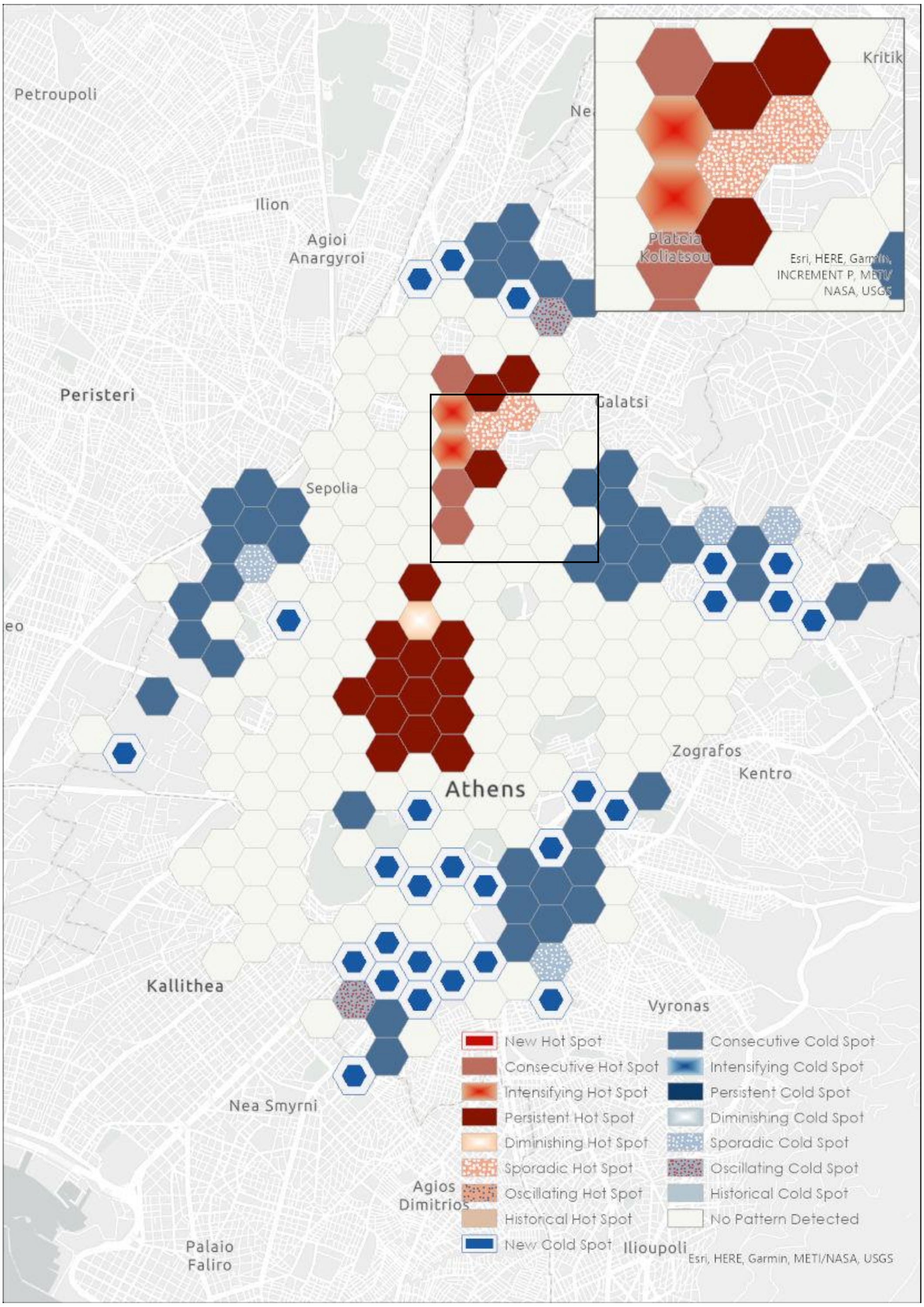


Figure 4.13: Space-time cube

The results indicate that there are sixteen persistent hotspots in the city, with thirteen of them gathered in the very centre of Athens, around Omonia square and the area of Exarcheia. In addition, there are three intensifying and two consecutive hotspots in the northern part of the city. This pattern was created using the parameters below.

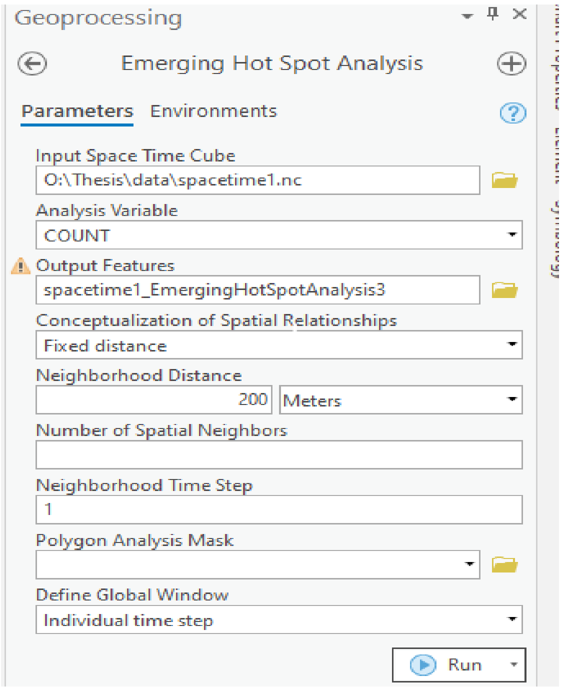


Figure 4.14: Hotspot analysis parameters

We can change the spatial relationship and use k nearest neighbour instead of a fixed distance. In this case, the results are as shown in picture 4.15 and the parameters as shown below. Notice that in this case, three new hotspots have appeared in random locations, while there are six persistent and fifteen sporadic hotspots.

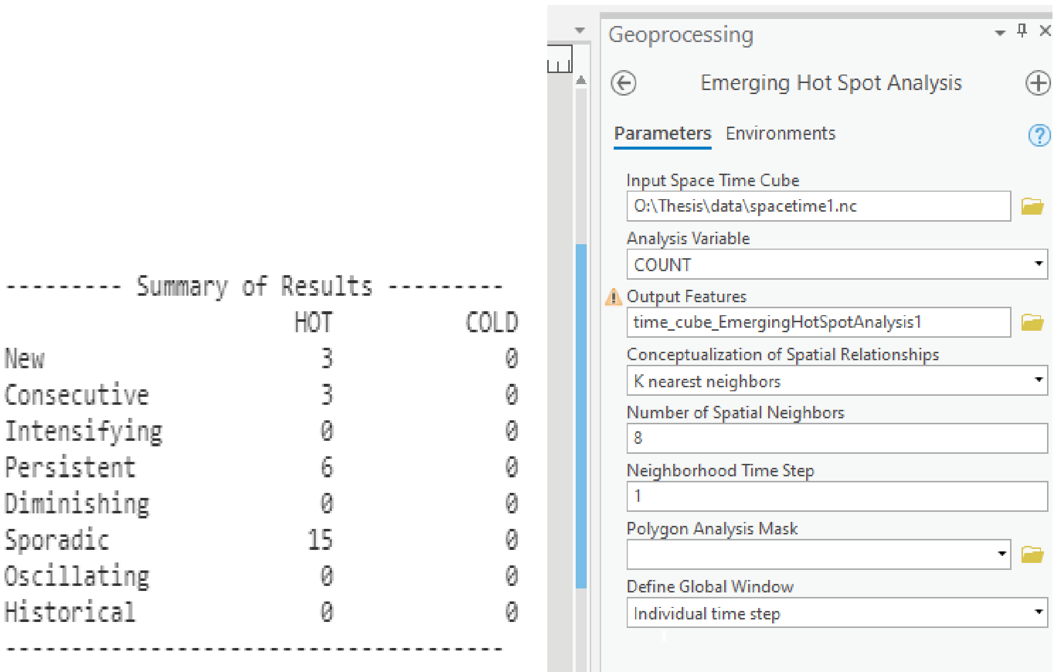


Figure 4.15: K nearest Hotspot analysis parameters

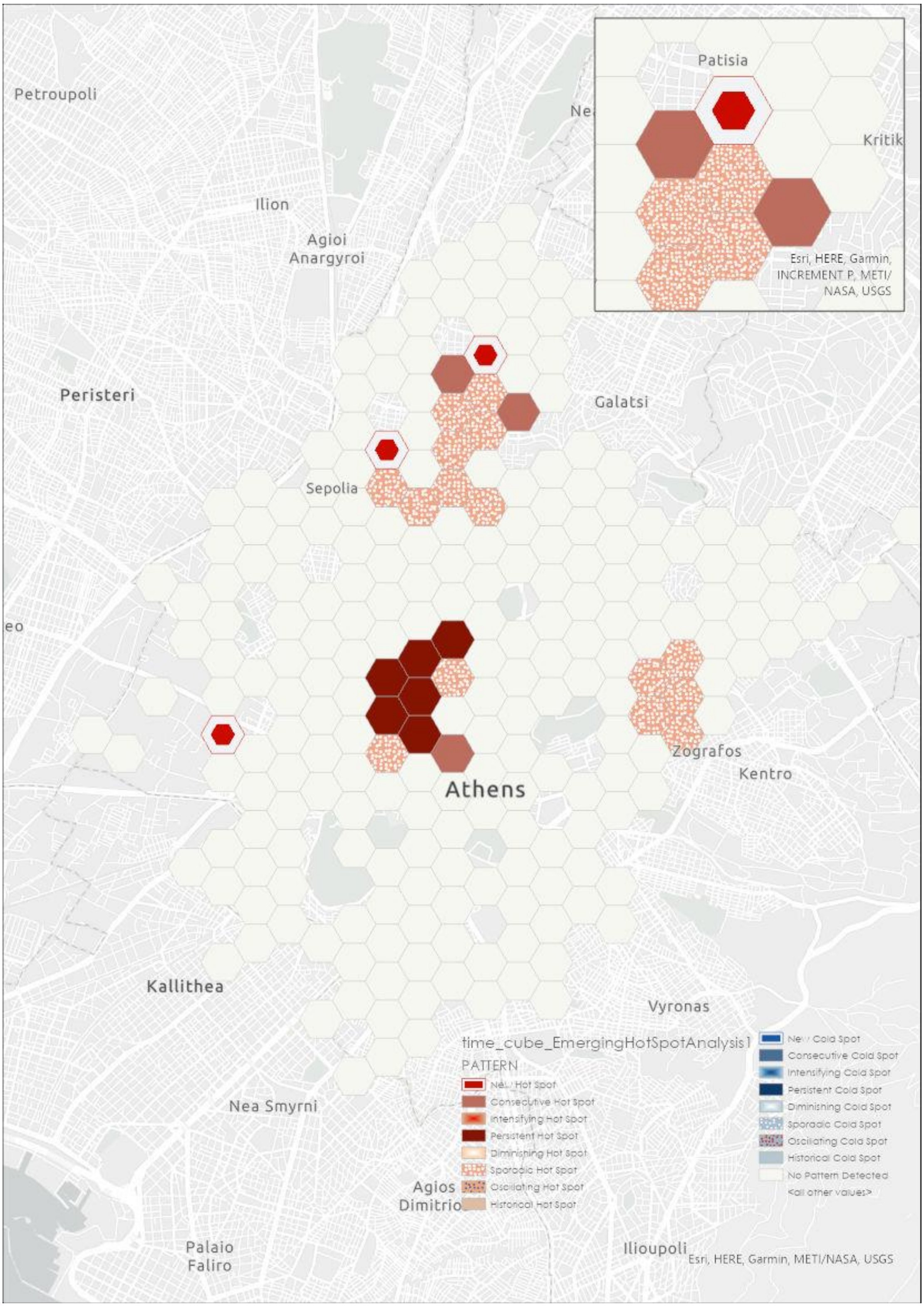


Figure 4.16: K nearest Space-time cube

In addition, every accident was projected to the nearest road segment in order to find the exact affected location of the network. The Snap tool was used to project the accidents in their nearest road. Near tool was used to see how far each accident was from the road segments. After analysing the crashes, it was decided that a 10m distance was appropriate as a mean distance for the tolerance needed at the Snap tool. Once the points were allocated on a road, the Spatial Join tool was used (figure 4.11), and the road network was examined in segments, and the summary of accidents was calculated in every segment through the year, determining the locations with the higher amount of accidents (hotspots).

Road segments with a high number of collisions per year are spotted in the city centre near Omonia square, especially on roads Peiraios-Stadiou-28h Oktovriou and Athinas, near Ampelokipoi around the junction Alexandras Avenue – Vasilissis Sofias Avenue and through all the Vassilissis Sofias Avenue, at Vasilissis Amalias Avenue, Suggrou Avenue as well as 28h Oktovriou street. This analysis spots that some road segments on the south part of Athens are high in accidents as well, which was not shown by the space-time cube analysis. Segment analysis may be used along with hourly/day data to create different maps for the days of the week, to see the traffic and crashes difference daily. In this case, the only data available provide information about yearly crashes making this analysis impossible.

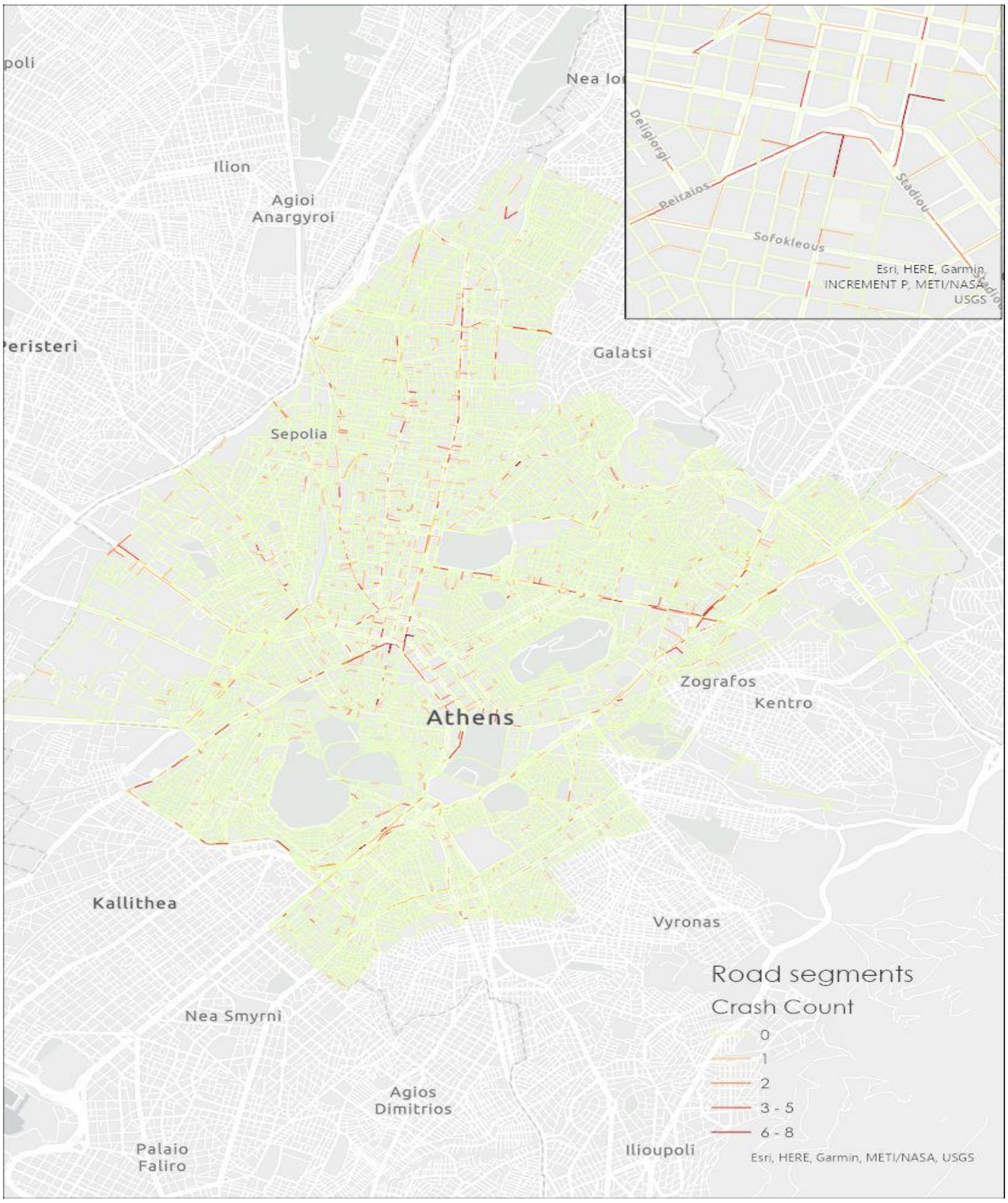


Figure 4.17: Road network segments and hotspots

Kernel density (figure 4.18) was also used to verify the high-density areas where the most accidents occurred through the years. Kernel Density analysis showed two very high-density areas, one in central Athens and one on the East around the area of Ampelokipoi. Four high-density areas were spotted around the city centre, on the East, around Alexandras Avenue segments and on the segments connecting the city centre and North Athens.

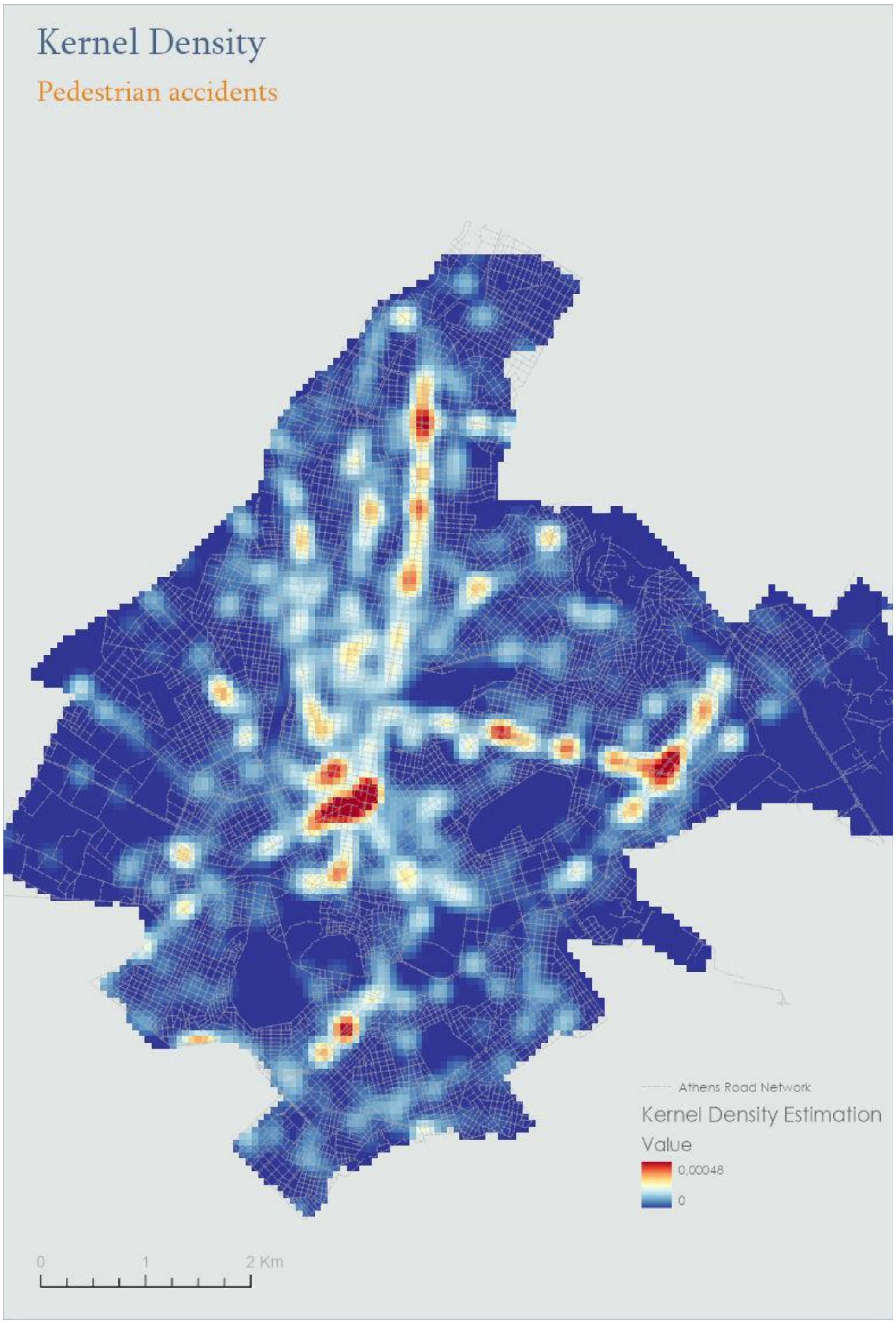


Figure 4.18: Kernel Density estimation of pedestrian accidents in Athens

Figure 4.19 shows the results of Kernel Density estimation of slight severity accidents. As expected, the results are nearly the same as those of the whole sample, as the slight severity accidents have the highest percentage of the sample.

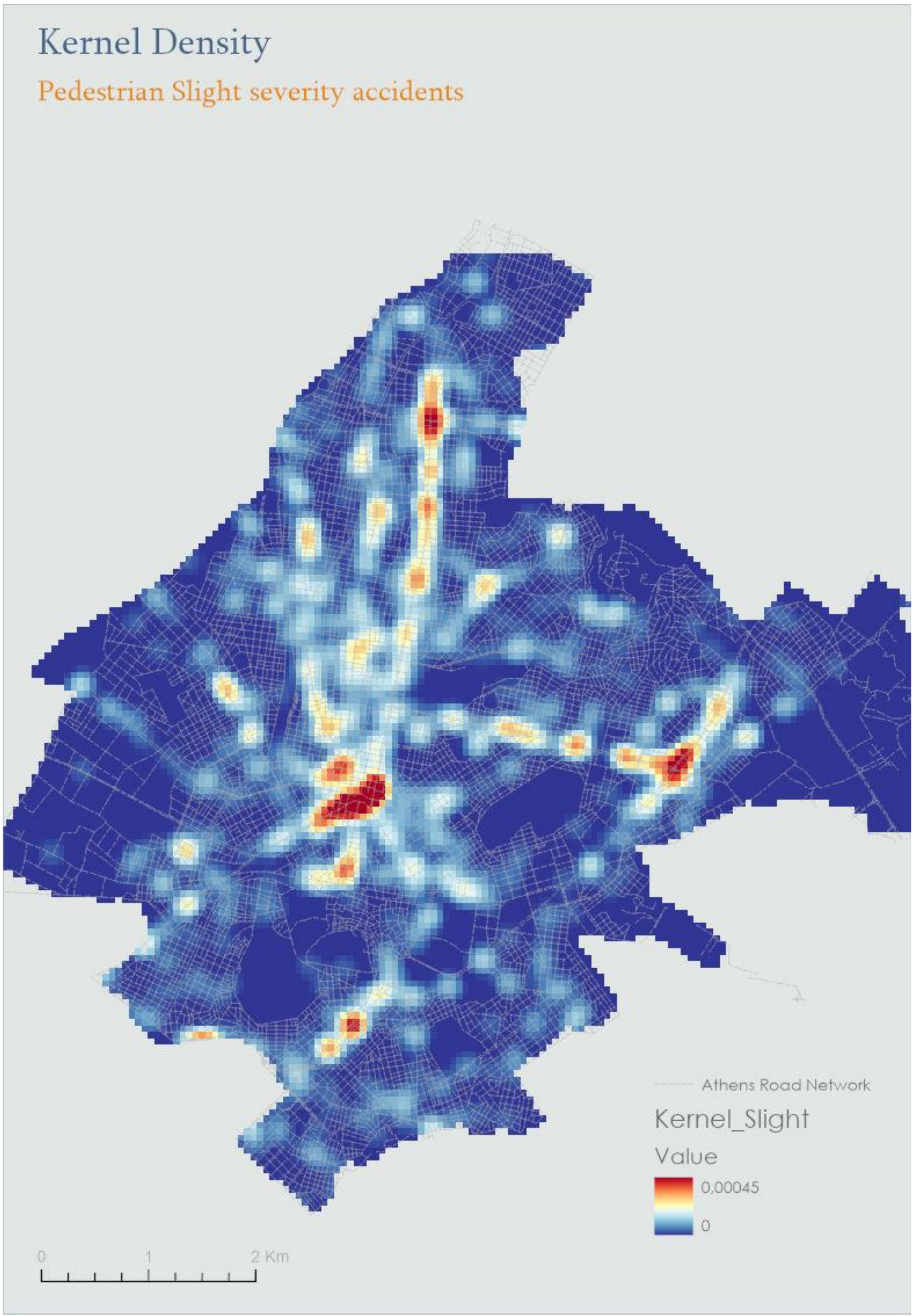


Figure 4.19: Kernel Density estimation of slight severity pedestrian accidents in Athens

In figure 4.20 are shown the results of Kernel Density estimation for the group of accidents with fatal/ serious severity. Central east network appears to concentrate most of the accidents of such severity, specifically along Alseksandras Avenue and Vasilissis Sofias Avenue. Another high-density location with severe accidents is spotted in the north part of the city near Galatsi.

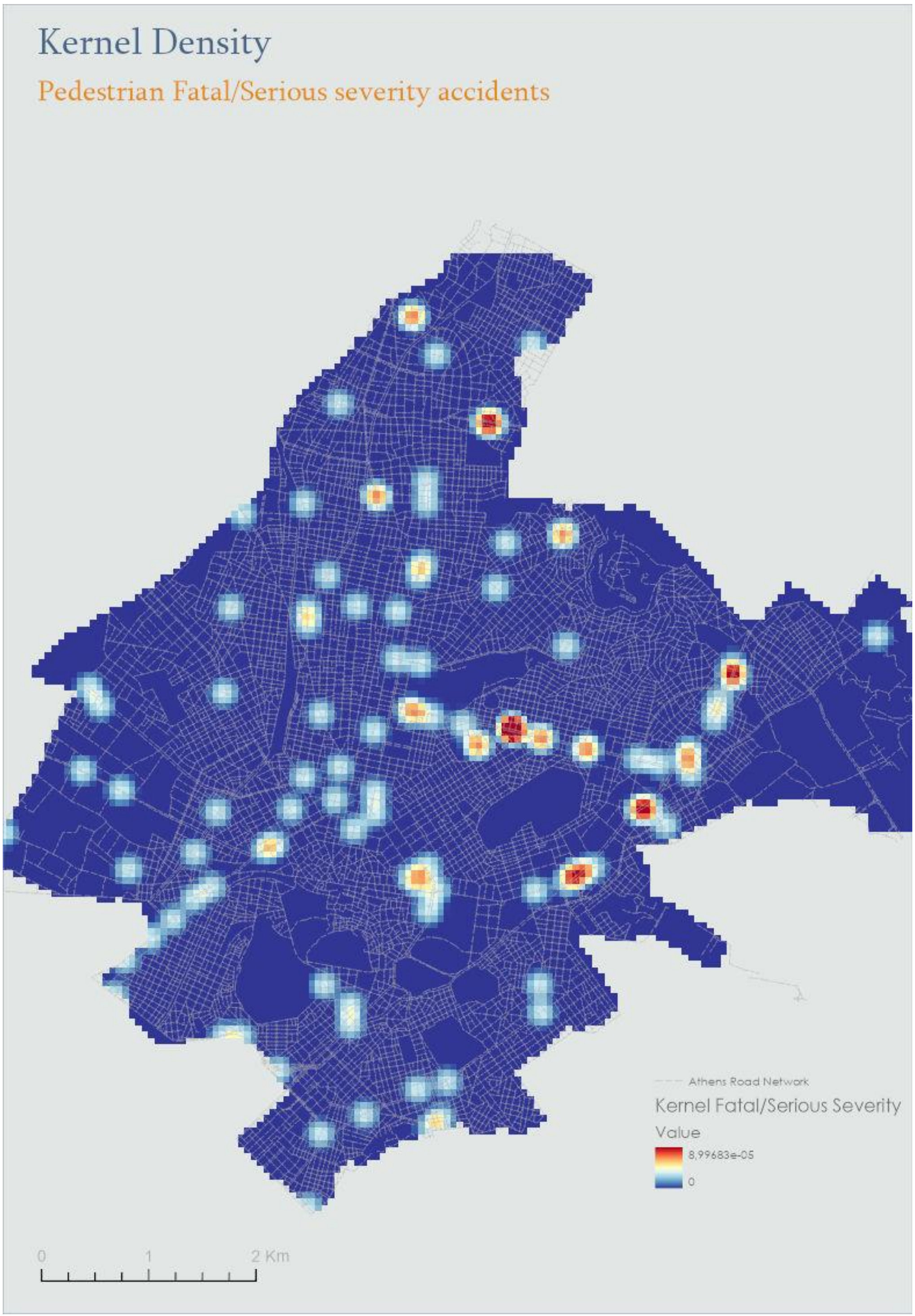


Figure 4.20: Kernel Density estimation of fatal/serious severity pedestrian accidents in Athens

4.2.1. Mean Centre

Statistical analysis can be performed using geostatistical indicators such as mean centre. At this point, the mean centre is used to observe its change of location through the years. Figure 4.21 shows Athens city centre as well as the accidents' mean centre which is located near the first. In addition, mean centres of the accidents of each year are displayed. Their locations are spotted to be, in general, very close to the average mean centre. There is a movement of the mean centre towards northern Athens on 2013-2014, towards north-west on 2015-2016, while 2011-2012 mean centre shows a movement towards the south part.

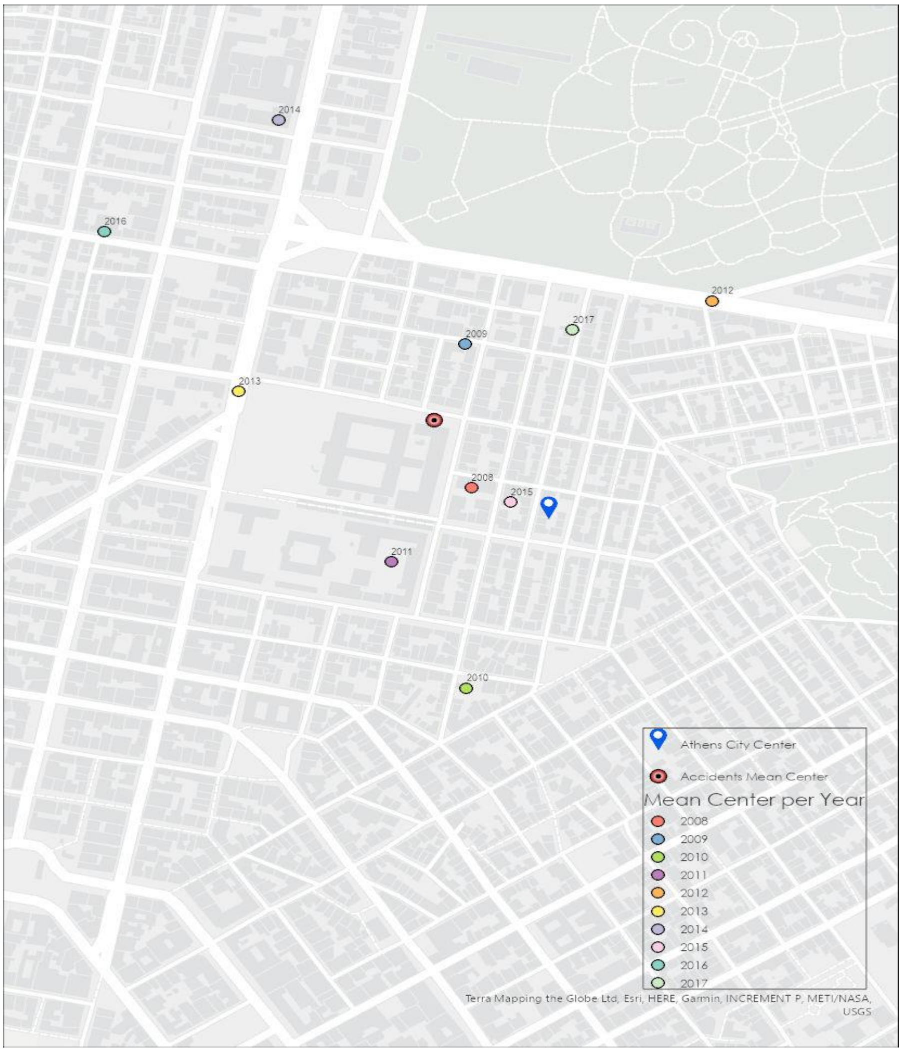


Figure 4.21: Pedestrian accidents' annual mean centre

The following three figures show the mean centres of the accidents as they are categorised by their severity. The categories of fatal and serious severity have a distribution of their own which is different from that of the whole accidents. On the contrary, the distribution of the slight severity accidents has the same pattern as that of the whole sample. This occurs because the slight severity accidents are those that cover the biggest percentage of the sample (figure 4.24). Fatal accidents were mainly located near the city centre. During 2010 and 2011, the fatal accidents mean centre moved slightly South, in 2016 it moved to the West part, while 2017 shows a considerable move to the North-East part of the city (figure 4.22).

Finally, the mean centre of serious severity accidents was located mainly near the city centre, except for 2017 when it is shown to be located in the Northern parts of the city.

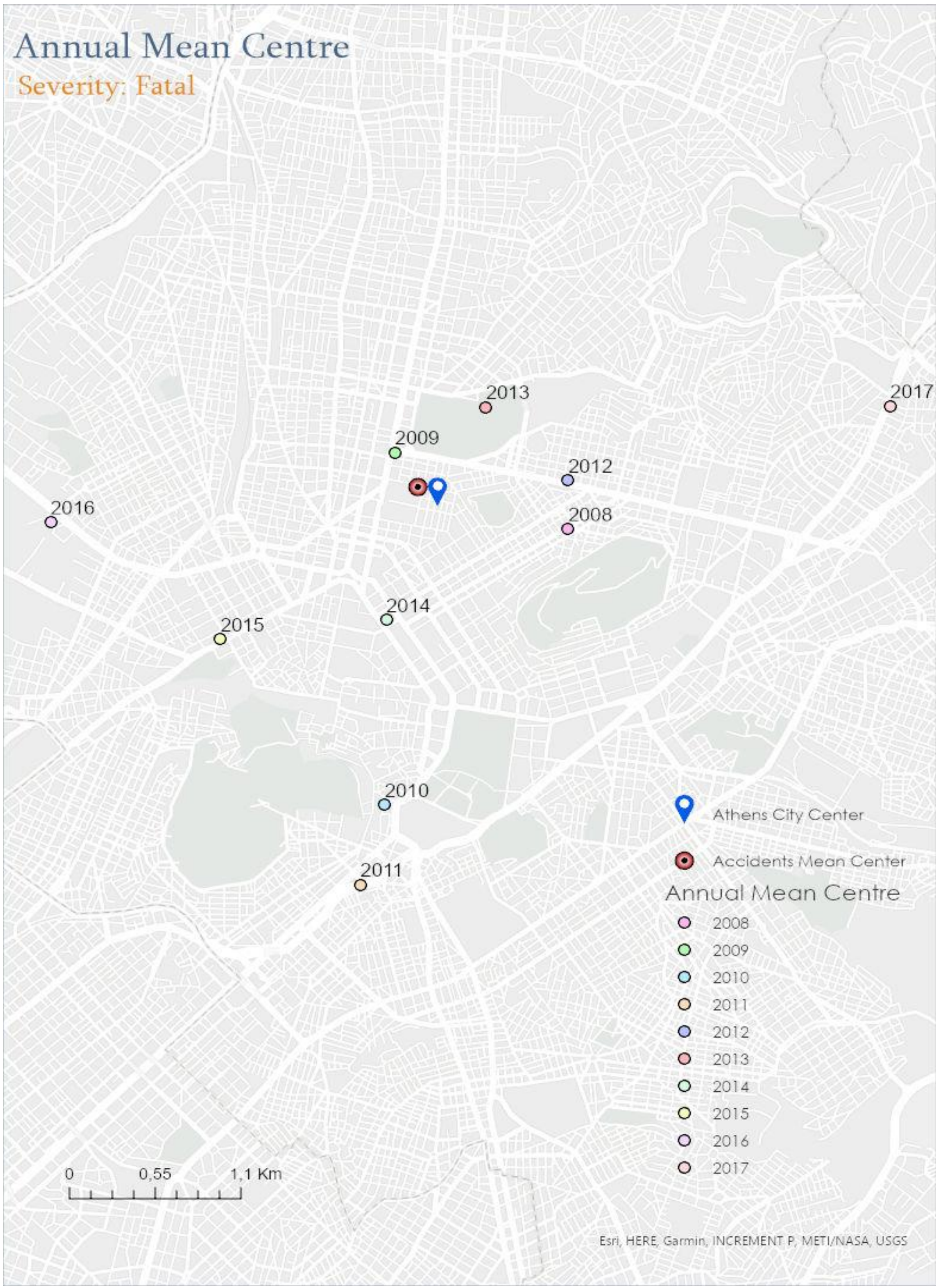


Figure 4.22: Pedestrian accidents' annual mean centre – Fatal severity

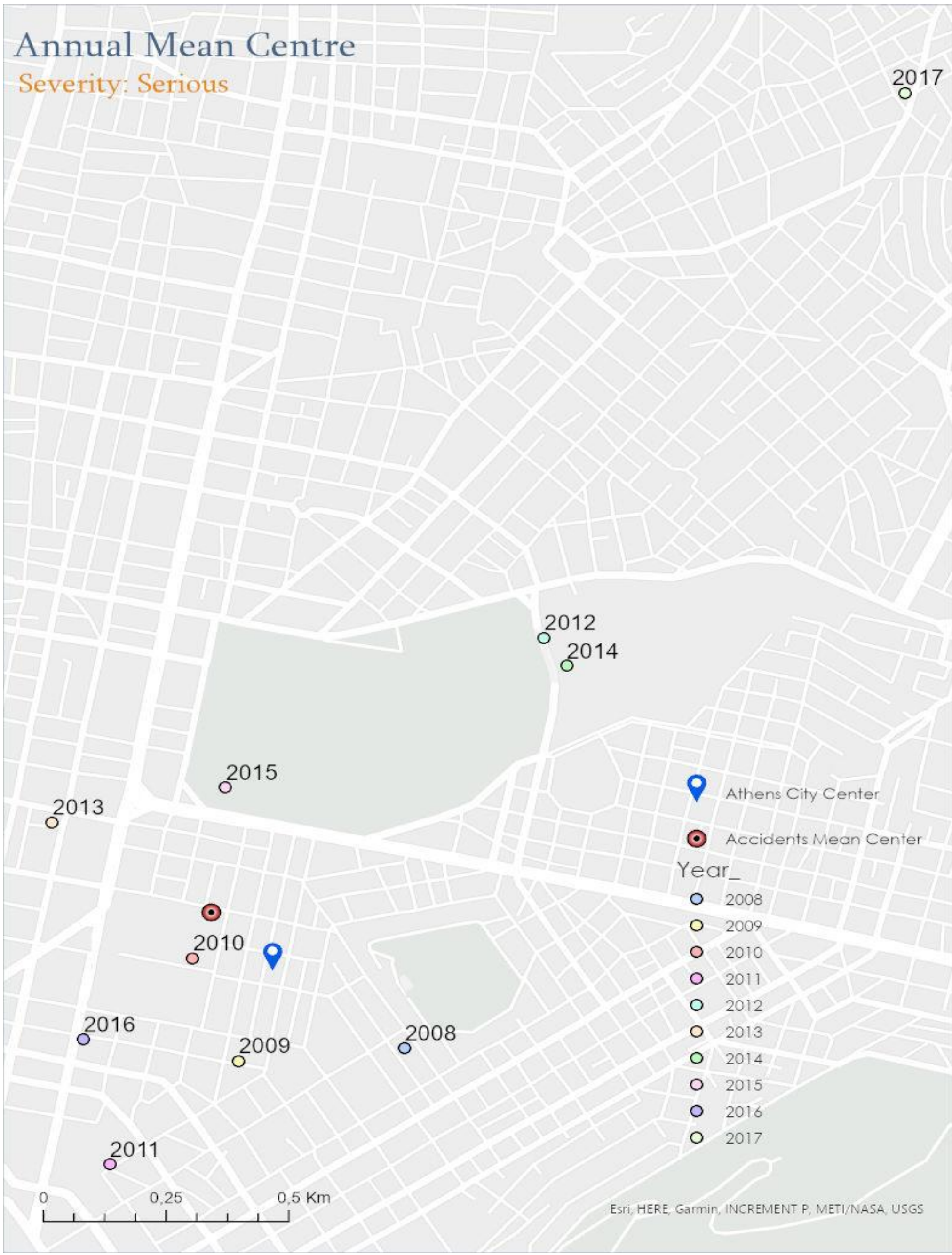


Figure 4.23: Pedestrian accidents' annual mean centre - Serious Severity

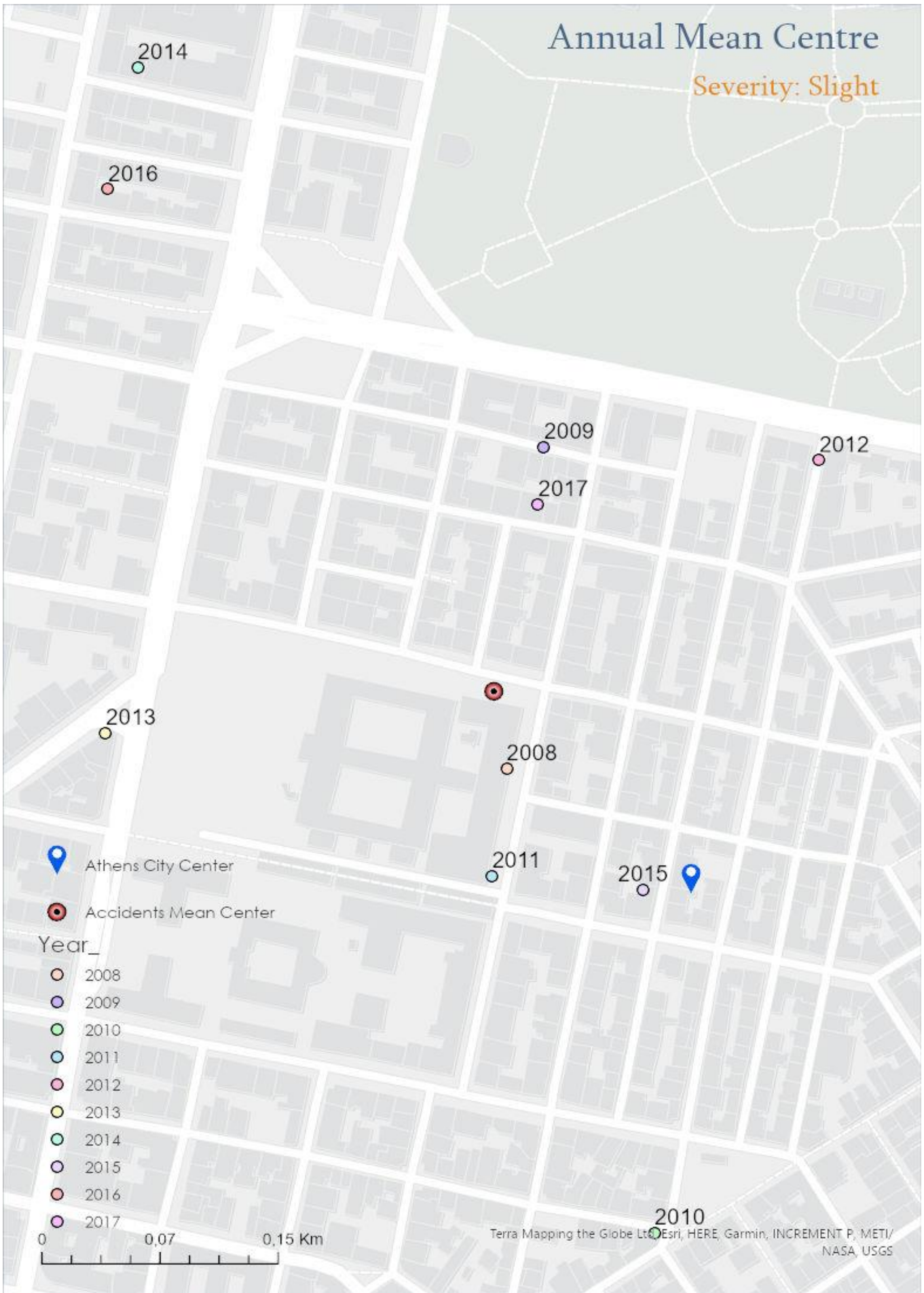


Figure 4.24: Pedestrian accidents' annual mean centre – Slight Severity

Along with the mean centre, the elliptical distributions of accidents per year were calculated as shown in figure 4.25.

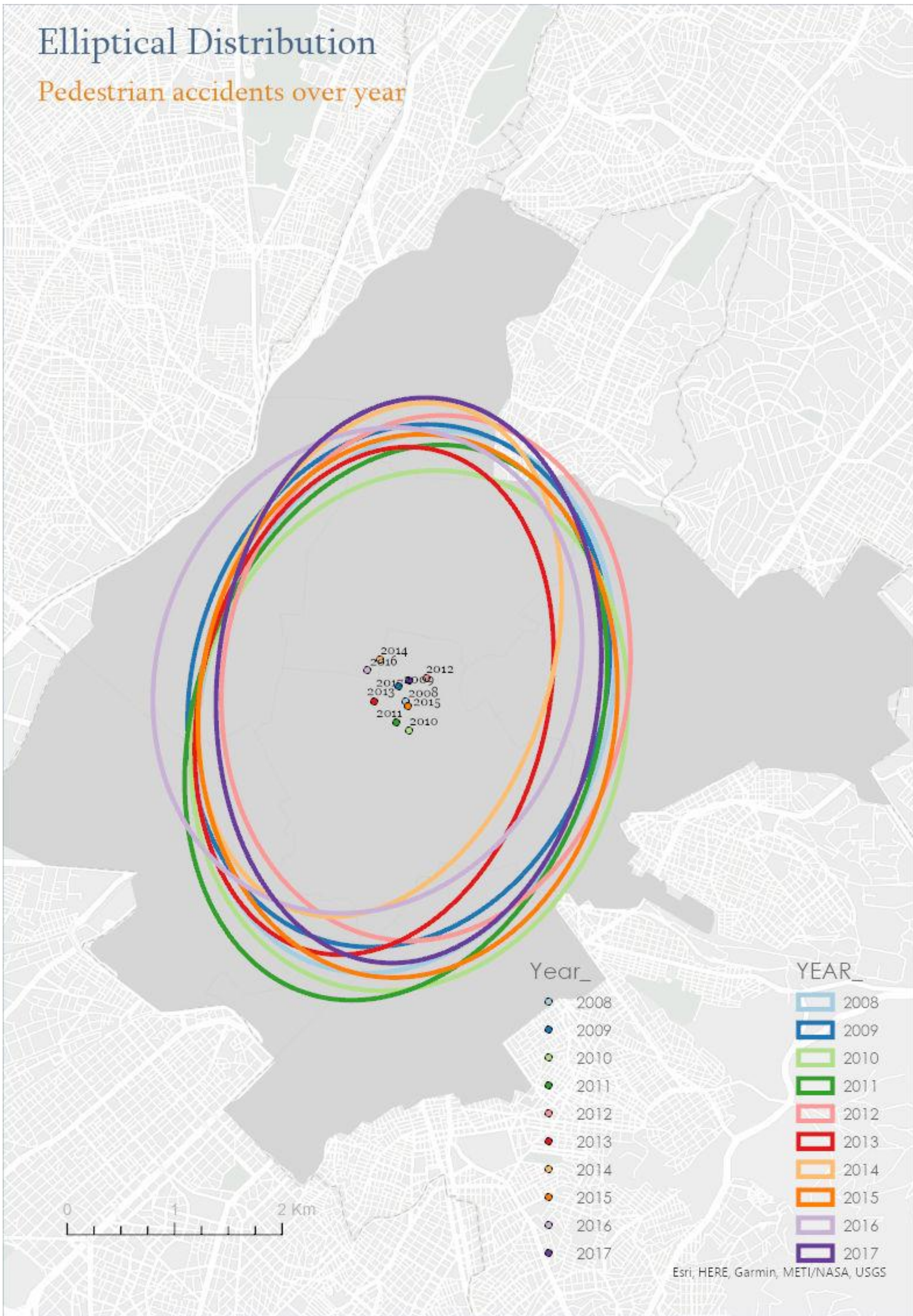


Figure 4.25: Elliptical Distribution of accidents per year

4.2.2. Local Moran's I

Global Moran's I results

Spatial autocorrelation indicators are also used to determine the spatial pattern of the sample points. Many different techniques are used in geography, but the most common are the quadrat analysis and the nearest neighbour analysis. Using the nearest neighbour analysis, a determination of the accidents' patterns was performed. Results from the values Z-score, P-value and the indicator Nearest Neighbour Ratio are shown in Figures 4.26 and 4.27. To run this technique, the Euclidean distance method was used in the city of Athens. Results show a clustered pattern with a p-value=0 and z-score=-24.

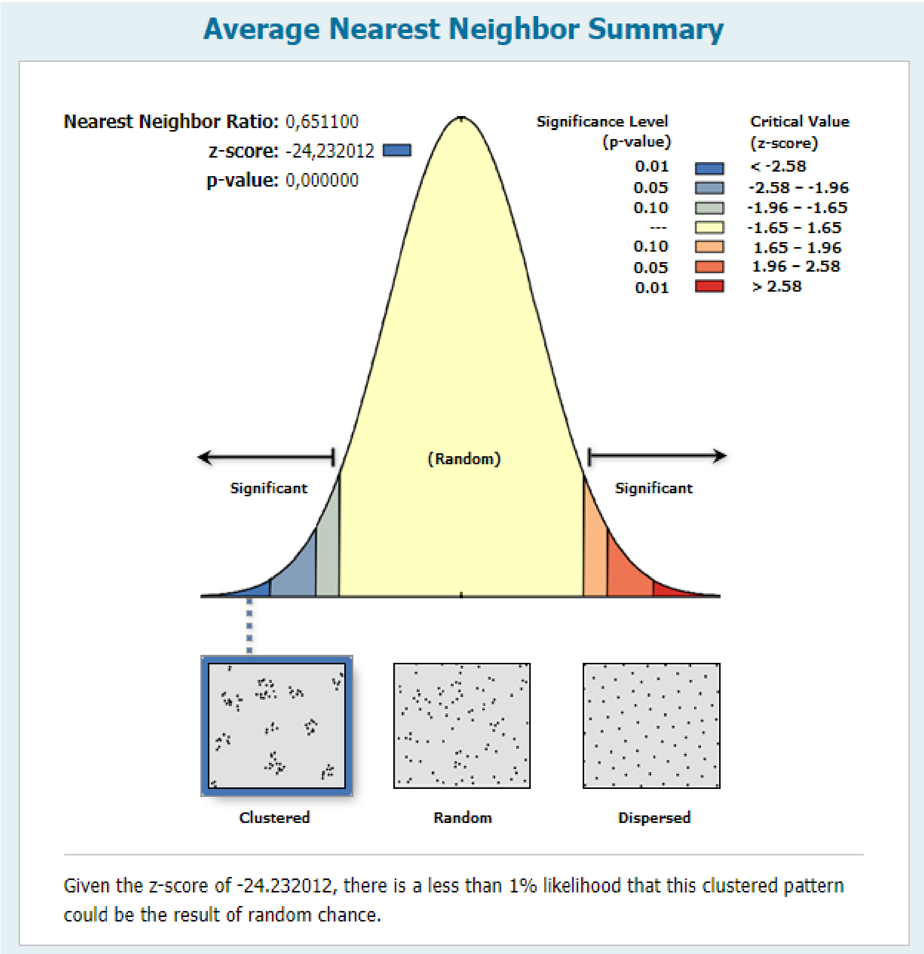


Figure 4.26: Average Nearest Neighbour results

Average Nearest Neighbor Summary

Observed Mean Distance:	55,9864 Meters
Expected Mean Distance:	85,9874 Meters
Nearest Neighbor Ratio:	0,651100
z-score:	-24,232012
p-value:	0,000000

Figure 4.27: Average Nearest Neighbour summary

Average nearest neighbour analysis was additionally conducted for the subcategories of the accidents, and the results are as shown below (Table 4.2). The overall sample is clustered in general and through each year. The results are the same for the sub-group of slight severity accidents, while the sub-group of fatal/serious severity accidents show a clustered pattern only on the overall sample of the group. Though each year, its pattern is random and, in 2014, dispersed.

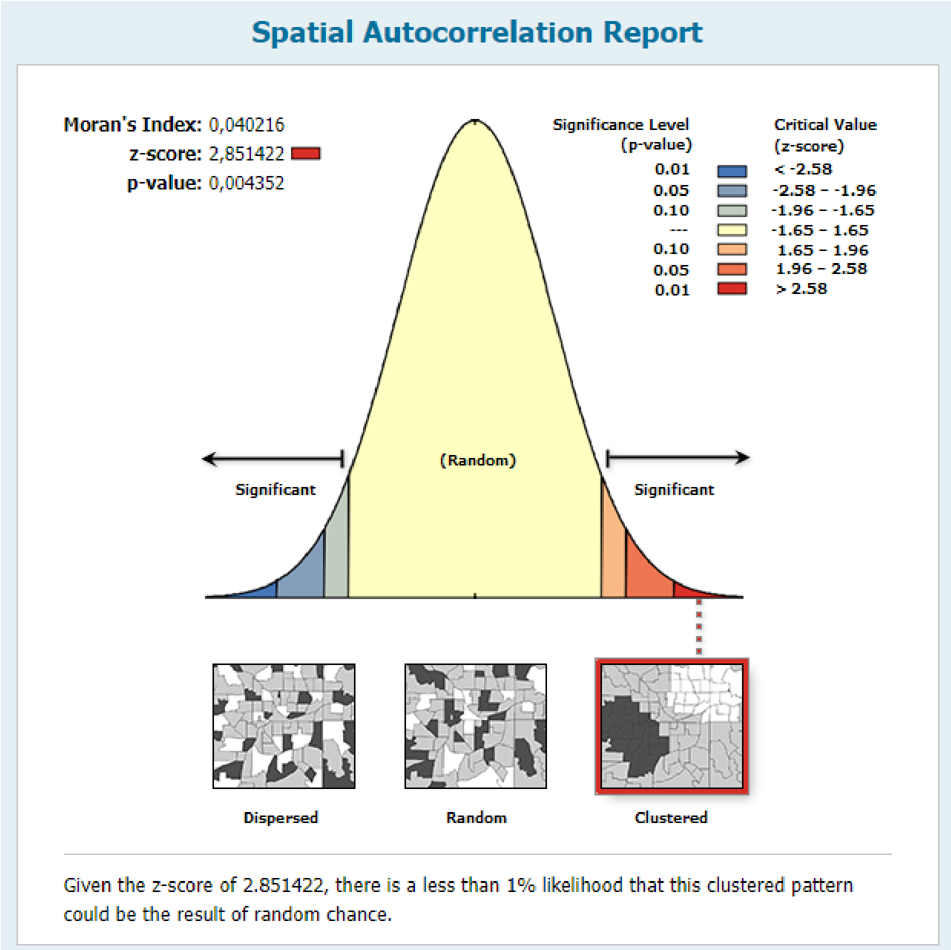
Table 4.2: Average Nearest Neighbour analysis results

Year	Analysis results	Accidents Sample results	Slight Severity Accidents Results	Fatal &Serious Severity Accidents Results
2008	Pattern	Clustered	Clustered	Random
	Ratio	0,849740	0,864480	1,216506
	Z-score	-3,878020	-3,350366	1,604157
	P-value	0,000105	0,000807	0,108679
2009	Pattern	Clustered	Clustered	Random
	Ratio	0,867954	0,902814	0,928832
	Z-score	-3,407938	-2,388225	-0,561358
	P-value	0,000655	0,016930	0,574554
2010	Pattern	Clustered	Clustered	Random
	Ratio	0,778450	0,785068	1,039504
	Z-score	-5,670596	-5,168456	0,346319
	P-value	0	0	0,729103
2011	Pattern	Clustered	Clustered	Random
	Ratio	0,777461	0,834406	1,093183
	Z-score	-5,599648	-3,982031	0,690420
	P-value	0	0,000068	0,489930
2012	Pattern	Clustered	Clustered	Random
	Ratio	0,820952	0,821462	1,208048
	Z-score	-3,920460	-3,725928	1,378750
	P-value	0,000088	0,000195	0,167972
2013	Pattern	Clustered	Clustered	Random
	Ratio	0,805338	0,783587	0,940772
	Z-score	-3,686599	-3,883788	-0,358311
	P-value	0,000227	0,000103	0,720110
2014	Pattern	Clustered	Clustered	Dispersed
	Ratio	0,777151	0,839230	1,442200
	Z-score	-4,220406	-2,917816	2,392733

	P-value	0,000024	0,003525	0,016723
2015	Pattern	Clustered	Clustered	Random
	Ratio	0,769184	0,797367	1,079077
	Z-score	-4,348936	-3,718217	0,338270
	P-value	0,000014	0,000201	0,735160
2016	Pattern	Clustered	Clustered	Random
	Ratio	0,657504	0,669393	1,133810
	Z-score	-6,453153	-6,066475	0,572405
	P-value	0	0	0,567048
2017	Pattern	Clustered	Clustered	Random
	Ratio	0,837228	0,833157	0,937370
	Z-score	-2,802540	-2,836947	-0,169444
	P-value	0,005070	0,004555	0,865447
Sample	Pattern	Clustered	Clustered	Clustered
	Ratio	0,651100	0,680273	0,783429
	Z-score	-24,232012	-21,259048	-4,345384
	P-value	0	0	0

Anselin Local Moran's I results

Subsequently, autocorrelation index Anselin Local Moran's I was performed, and the results are shown in a map (figure 4.28), where every point shows the importance of other similar values near it. The index is used to spot the significant locations of the network with accidents in the past, now or shows a timelessness. The index was performed for all the samples, the slight severity accidents group and the fatal/serious severity accidents group. Results were similar for the first two categories and different for the third one (figure 4.30), with the first two appearing to have a clustered pattern, while the third one has a random one.

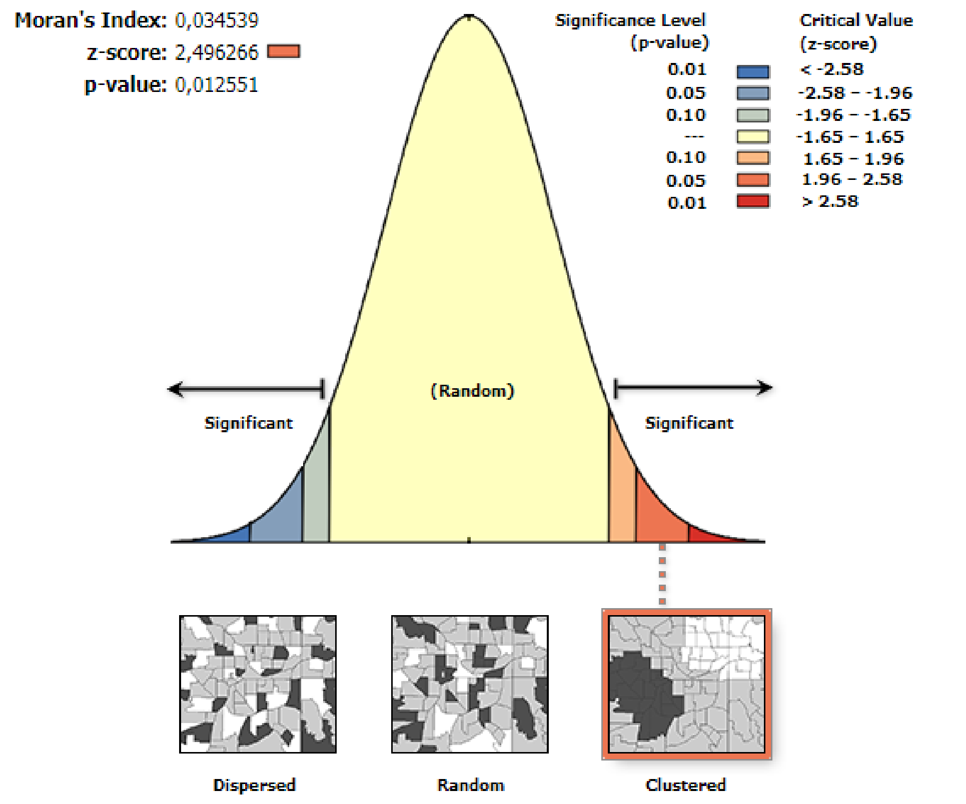


Global Moran's I Summary

Moran's Index:	0,040216
Expected Index:	-0,000759
Variance:	0,000207
z-score:	2,851422
p-value:	0,004352

Figure 4.28: Anselin Local Moran's I summary of the whole sample

Spatial Autocorrelation Report

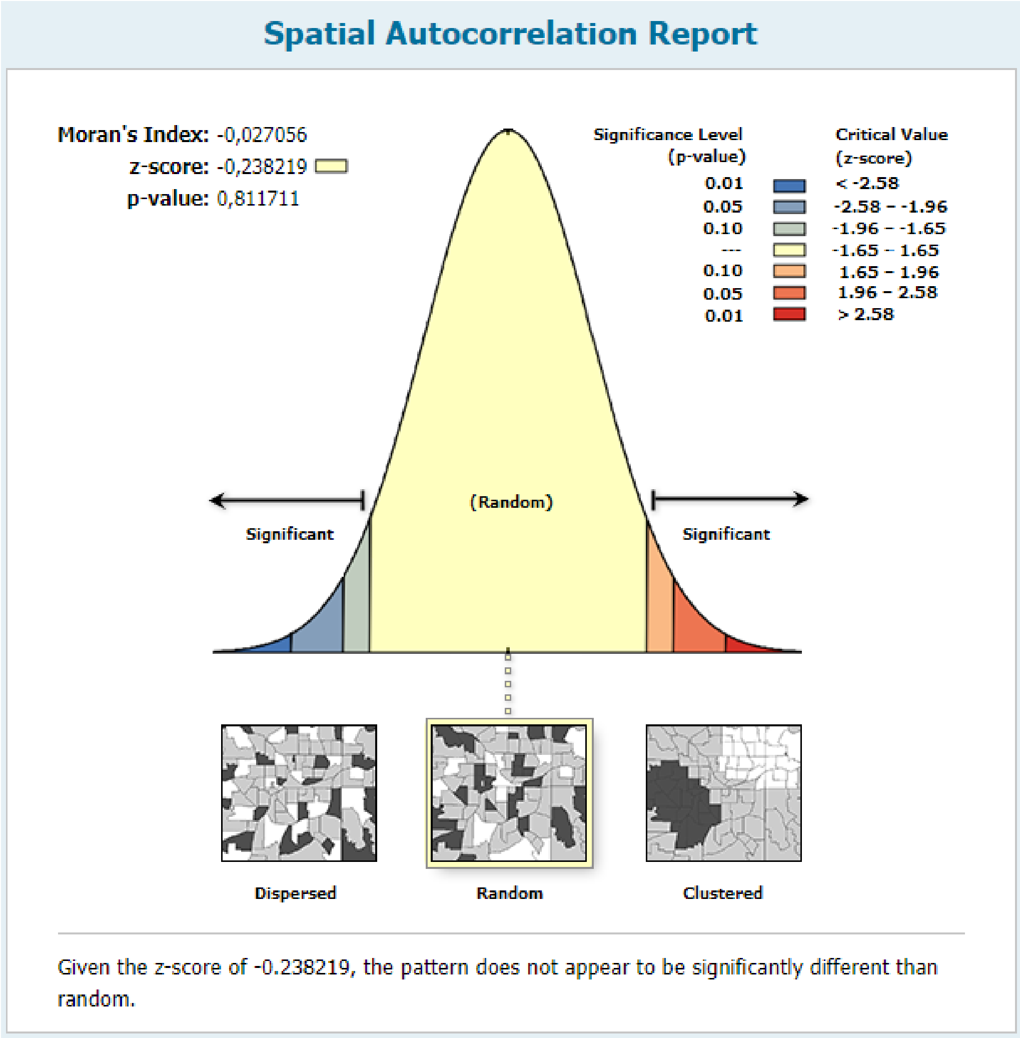


Given the z-score of 2.496266, there is a less than 5% likelihood that this clustered pattern could be the result of random chance.

Global Moran's I Summary

Moran's Index:	0,034539
Expected Index:	-0,000829
Variance:	0,000201
z-score:	2,496266
p-value:	0,012551

Figure 4.29: Anselin Local Moran's I summary of slight severity accidents



Global Moran's I Summary

Moran's Index:	-0,027056
Expected Index:	-0,009174
Variance:	0,005635
z-score:	-0,238219
p-value:	0,811711

Figure 4.30: Anselin Local Moran's I summary of fatal/serious severity accidents

The following three figures (4.31, 4.32, 4.33) display the outliers as displayed from the Anselin Local Moran's I for the three different groups of accidents.

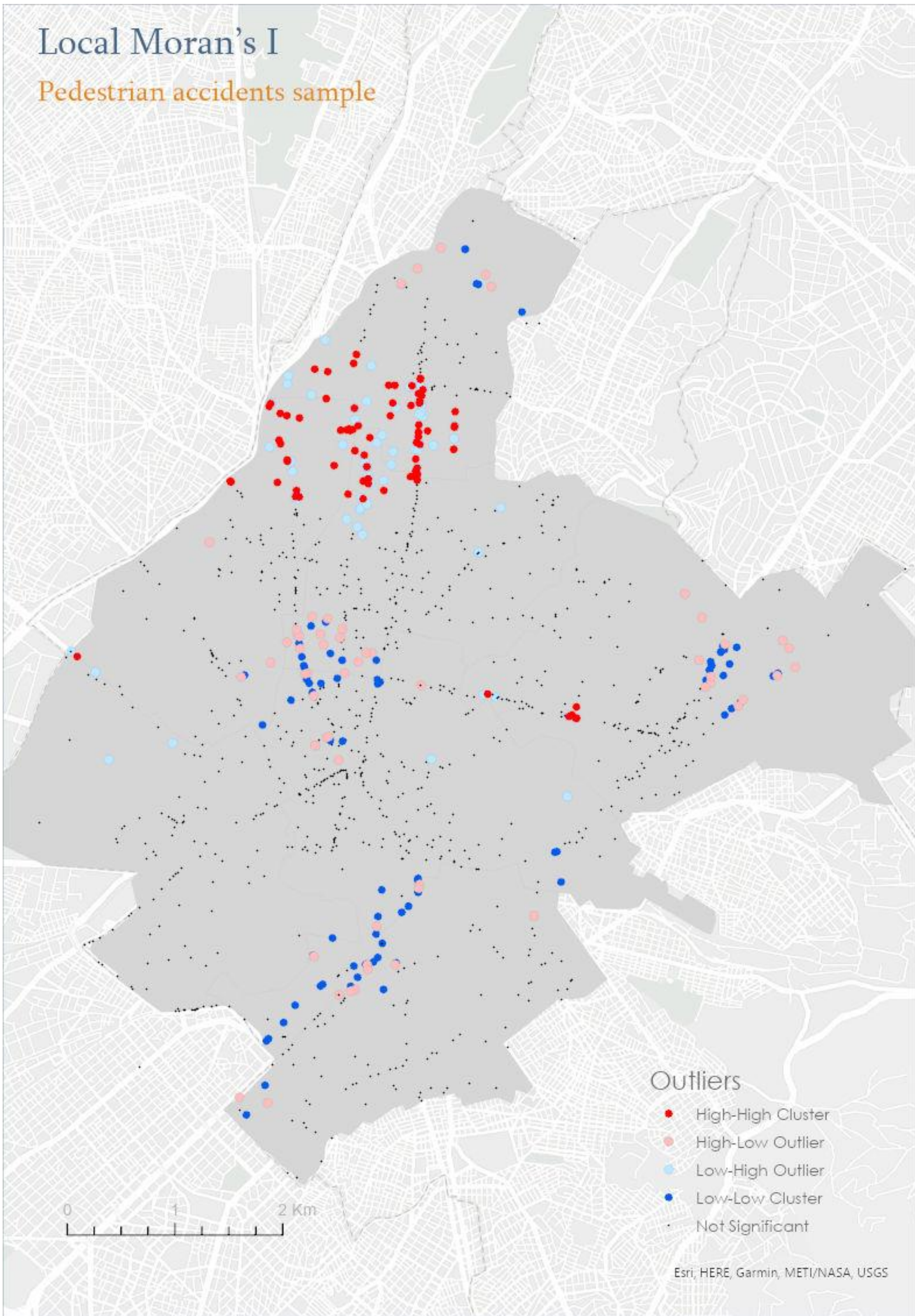


Figure 4.31: Local Moran's I whole accidents sample

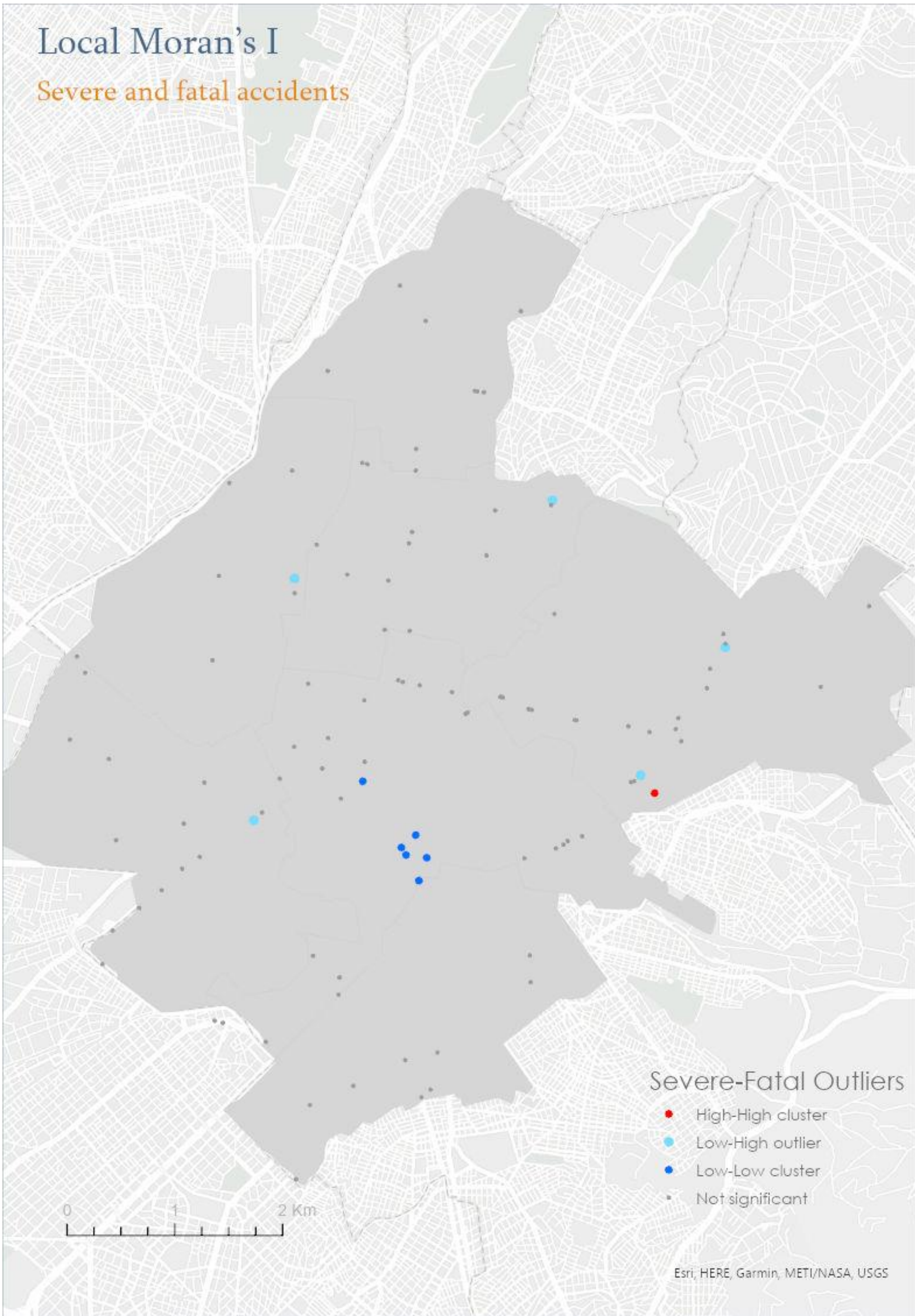


Figure 4.32: Local Moran's I fatal and serious severity accidents

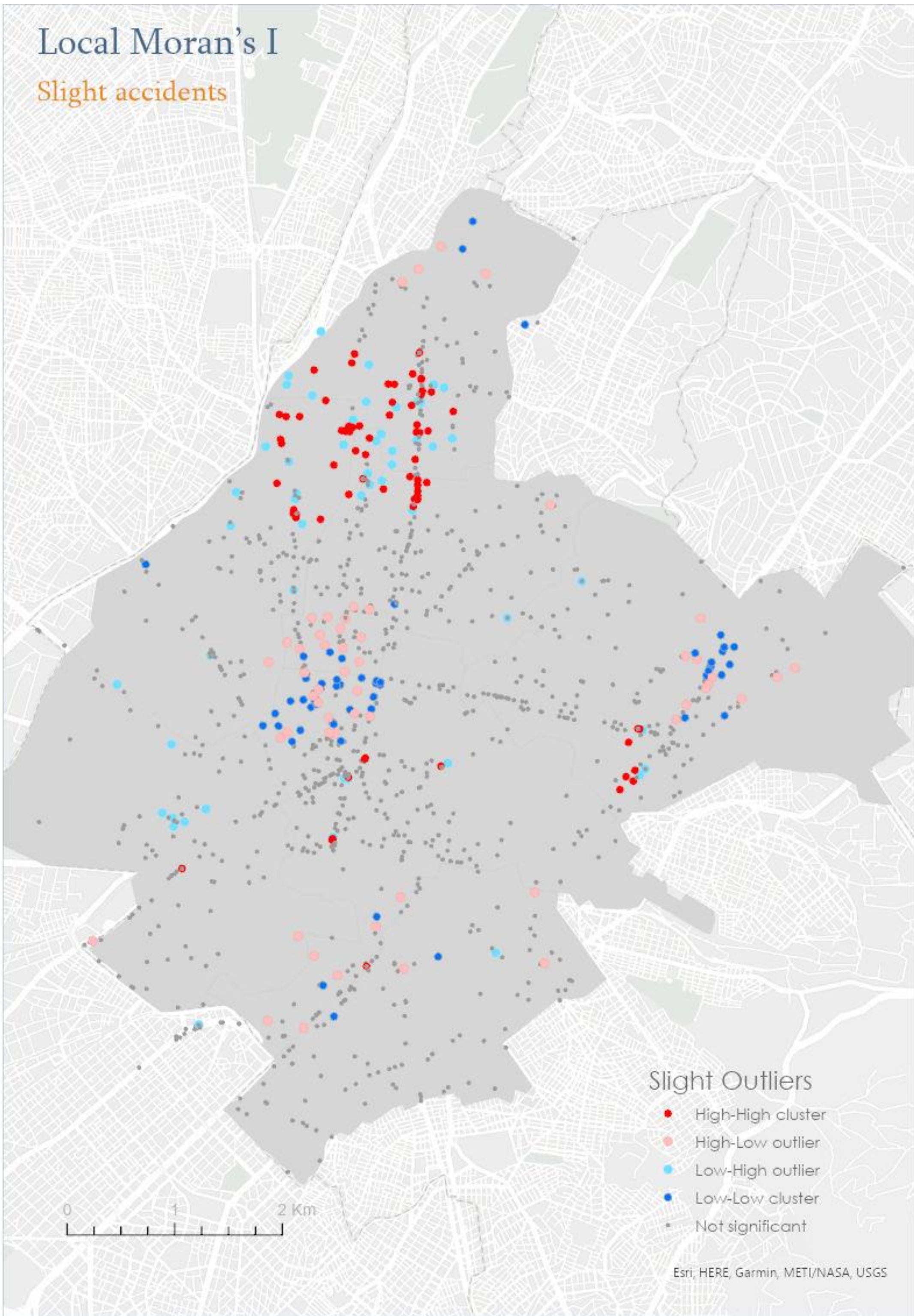


Figure 4.33: Local Moran's I slight severity accidents

4.3. Network Analysis of pedestrians' walkability

Building the network

To perform network analysis on ArcGIS, it is required to use the Network Analyst Extension. In addition, it is needed a solid road network which does not consist only of just any line data set. The road network is built using a line data set in the Build Network tool. During this process, all necessary nodes are created for the intersections and connectivity (figure 4.34). Lastly, the analysis requires a data layer of points called facilities, which in this case are the locations of the accidents. The network analysis is needed to better understand the walkability of pedestrians in the network. It is difficult to stimulate pedestrian walkability as it is difficult to predict the persons' reactions in different situations and the exact routes they are going to perform. However, it is possible with the network analyst to generate the zones that a pedestrian can reach through walking by either selecting a certain distance from a start point or the time frame within which he will be walking.

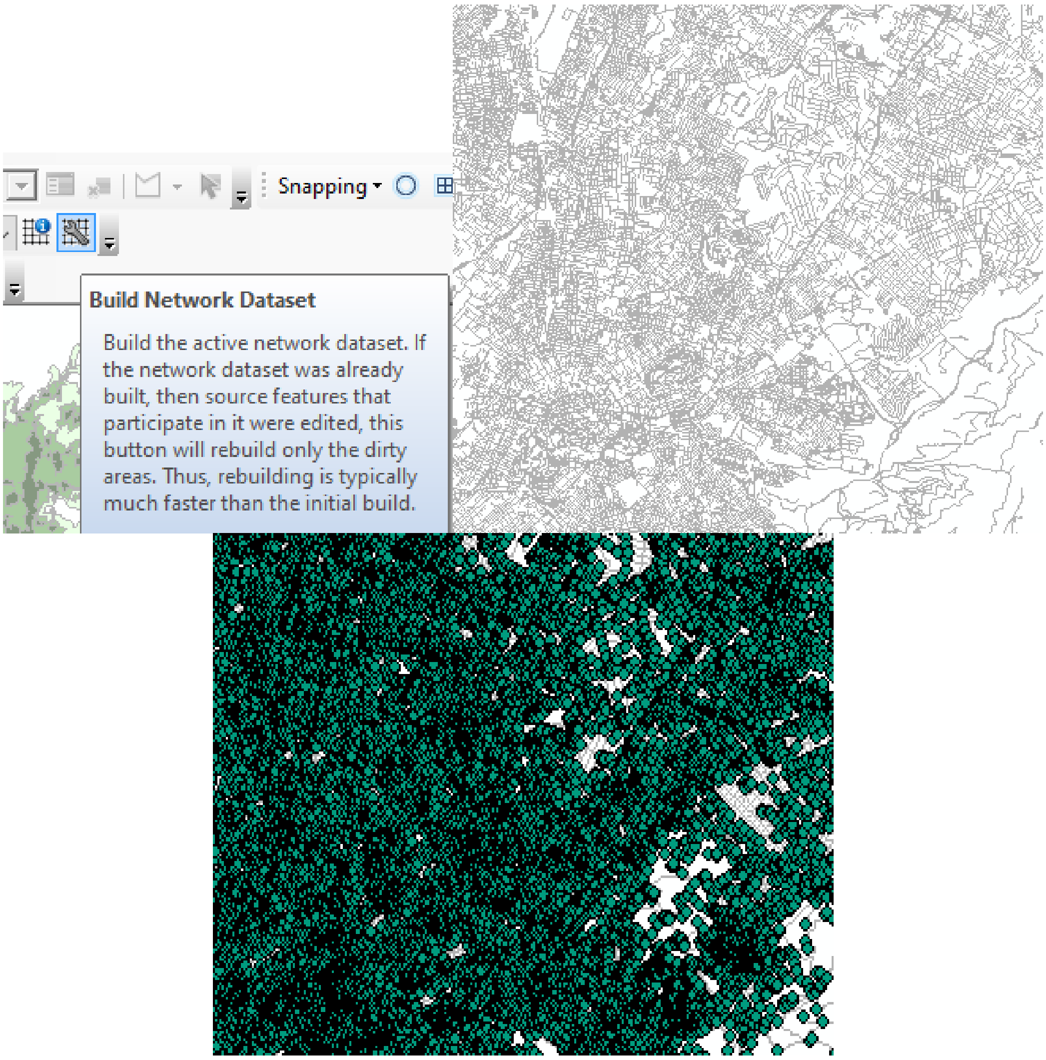


Figure 4.34: Building the Network

Creating the service areas

Whether you work on ArcGIS Map or ArcGIS Pro, the steps are the same. To create a new service area, the new service area tool should be selected from the Network Analyst (figure 4.35). The table of contents opens a service area analysis window. This will also appear at the network analyst window along with six network analysis classes: Facilities, Lines, Polygons, Point Barriers, Line Barriers and Polygon Barriers (figure 4.35).

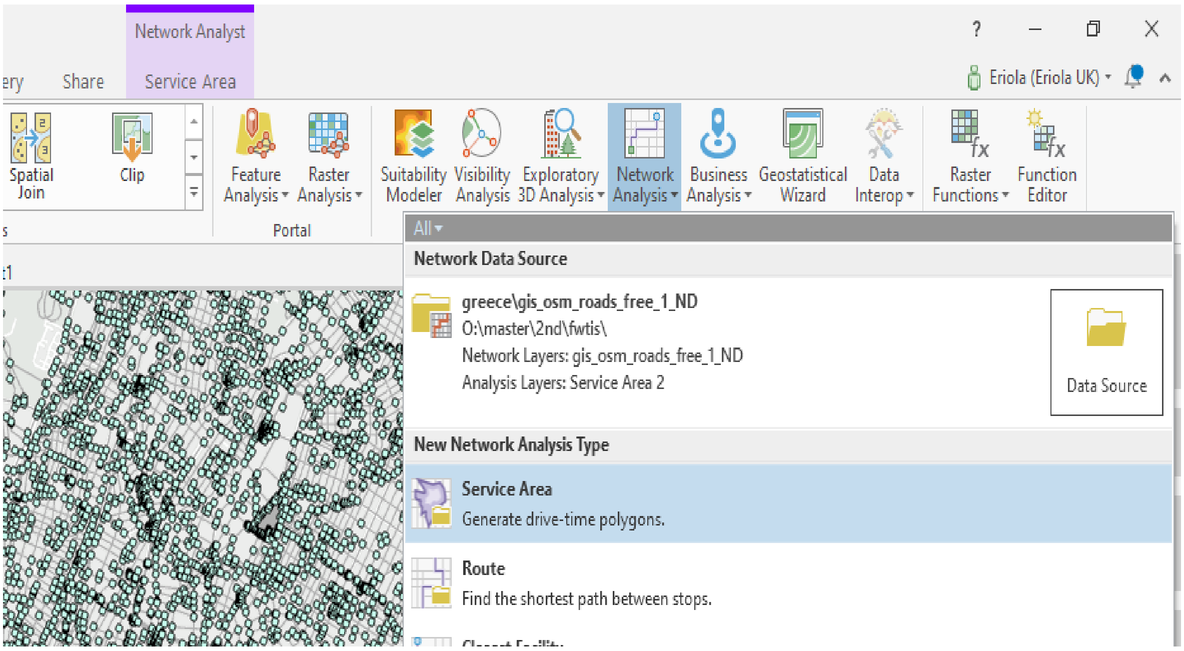


Figure 4.35: Service area generation

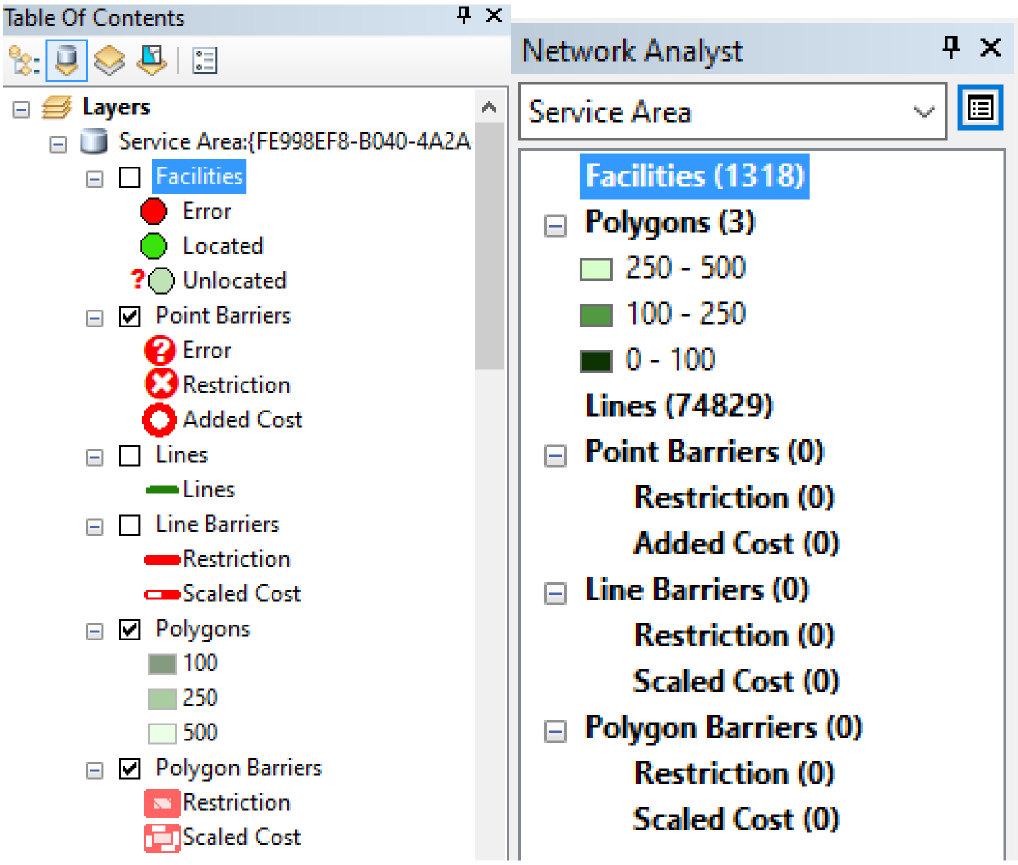


Figure 4.36: Network Analyst contents

Adding facilities

Figure 4.37 shows how the facilities (accidents' locations) were added to the network. With a right-click on the Facilities load locations option is shown at the menu. There are some extra options to configure before loading the facilities, such as setting the title of the network, whether the departure will be on the left side of the road or the right one, etc. However, most of these options are mainly to be considered when the network is being designed for vehicles' movement.

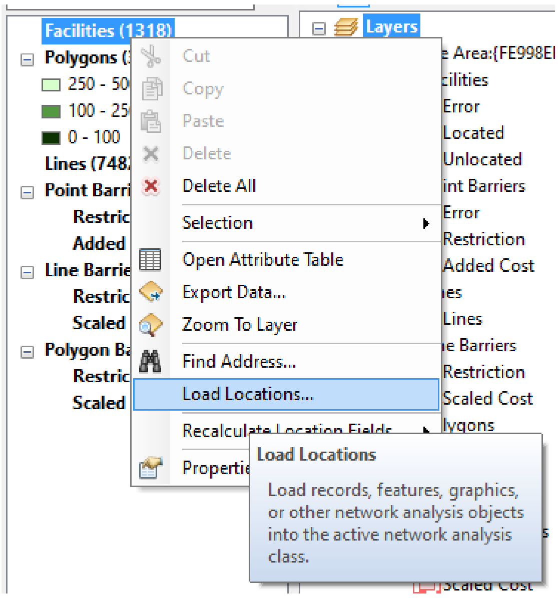


Figure 4.37: Loading the facilities

Setting up service areas

After the facilities are loaded, there are some settings to be considered in order to solve the network. Firstly, the distances that are to be checked from the location of the accidents should be set in a normal length considering the distance a pedestrian can walk. Also, as the analysis will involve land uses and services near the accidents, the distance of the impact should be considered as well.

The service area properties open a new window with different settings for the network. Figure 4.38 shows the settings used for the impedance, which in this case was the length in meters. In addition, the brakes used are 100m, 250m, 500m considering the fact that the network is set for pedestrian movement. There are no restrictions as the pedestrians can move easily in any direction.

Polygon generation settings (figure 4.39) are configurations done about the output of the polygons. Three kinds of polygons can be generated. The generalised, which are quickly generated with reasonable accuracy, the detailed, which have more accuracy but need more time to build, and the trim polygons, which have trimmed down edges. There are also options to create overlapped, merged, generated rings and disks from the overlap type. Finally, the line generation tab was checked, as it is vital to determine the reachable areas by the impedance parameter. The service area lines are more representative than the service areas as it shows exactly how far a facility can reach.

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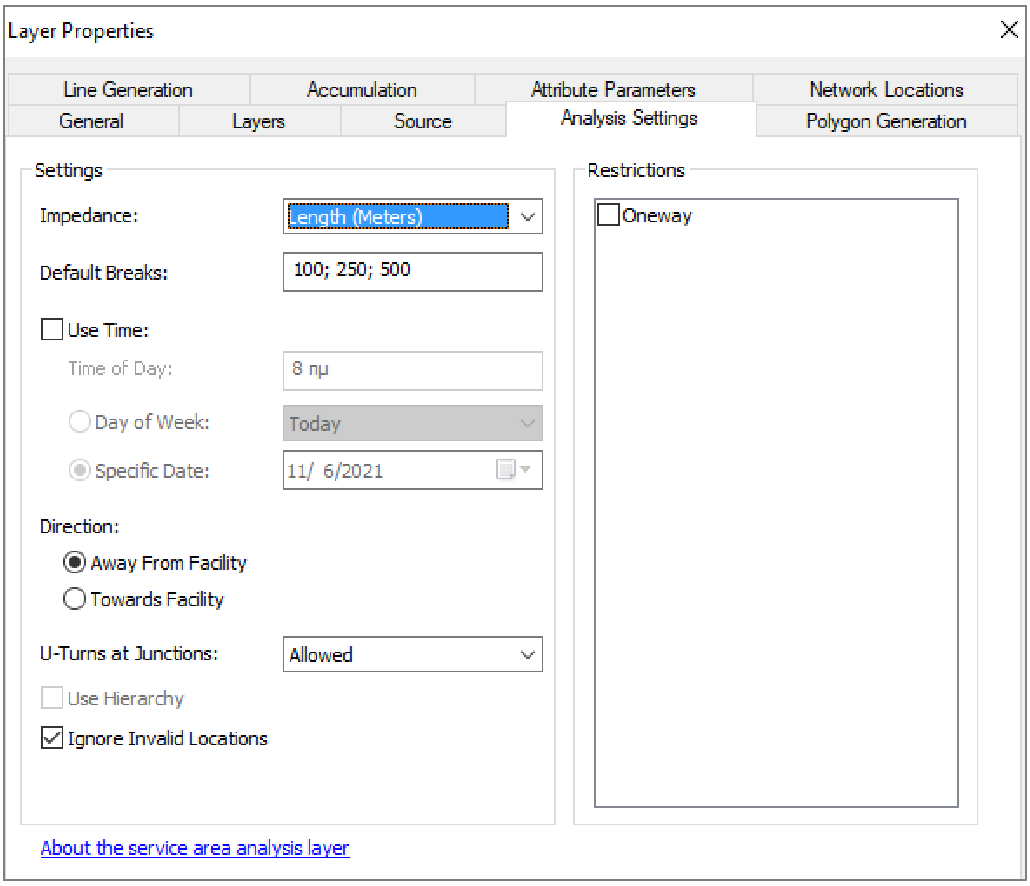


Figure 4.38: Setting service area properties

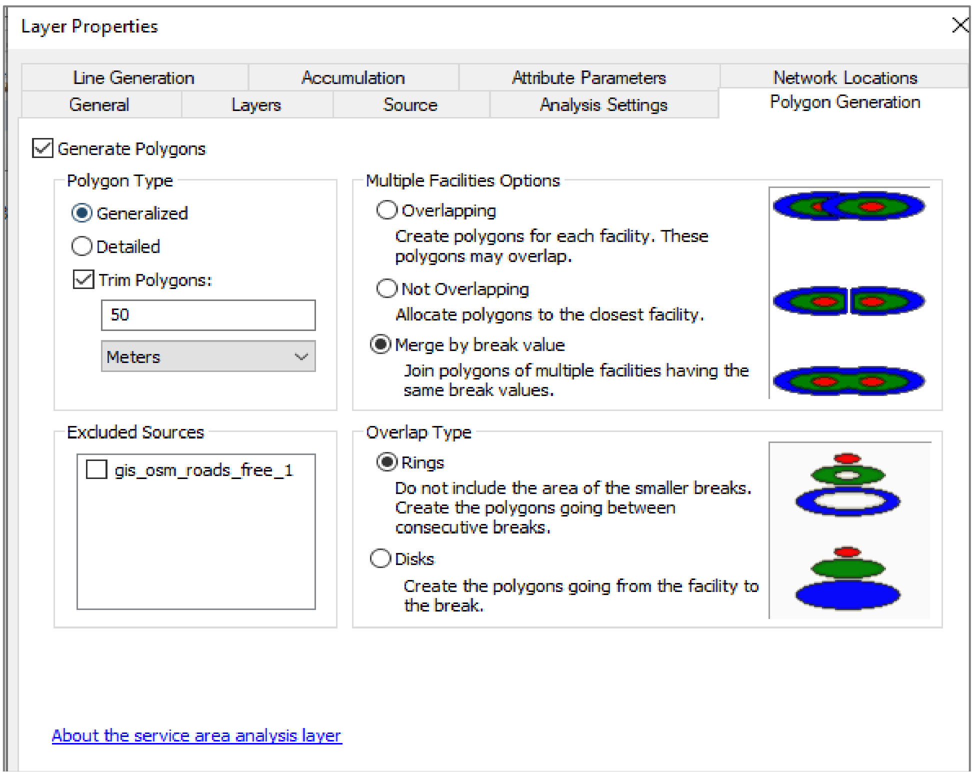


Figure 4.39: Polygon generation properties

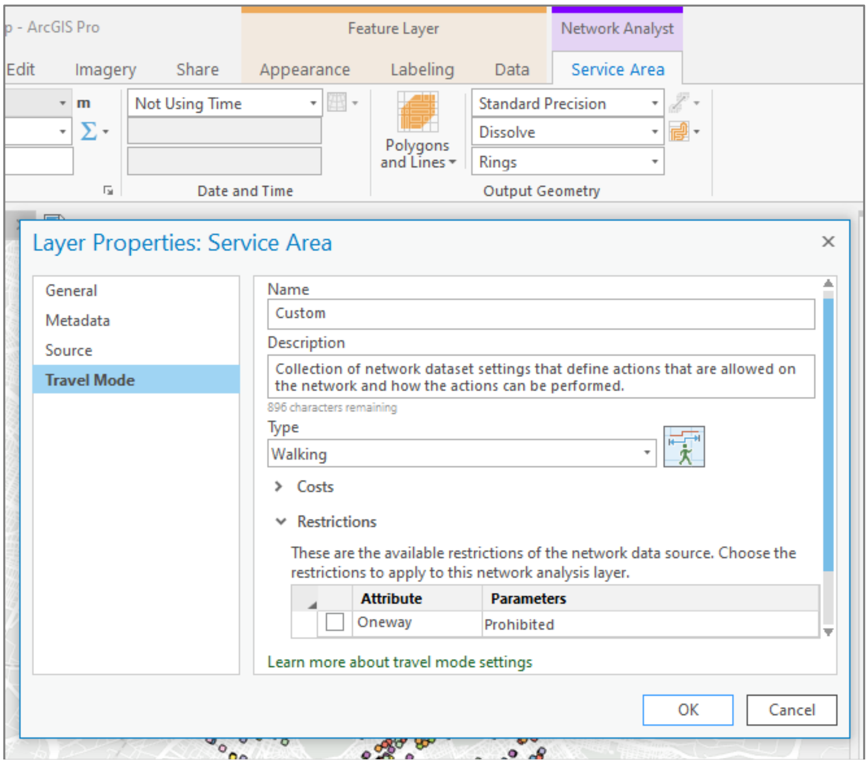
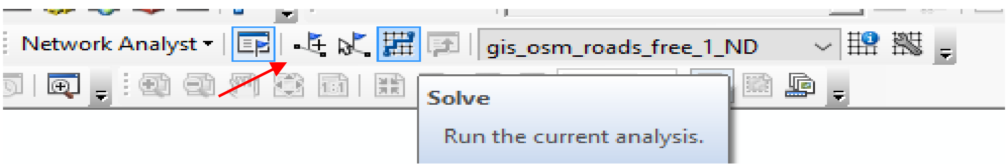


Figure 4.40: Selecting walking as travel mode

Solving the network

After setting all the parameters of the analysis, the network can be solved. The map of figure 4.41 shows the generated polygons that were created by the criteria set in the previous steps. As shown, most of the areas are reachable within 100meters walking distance.



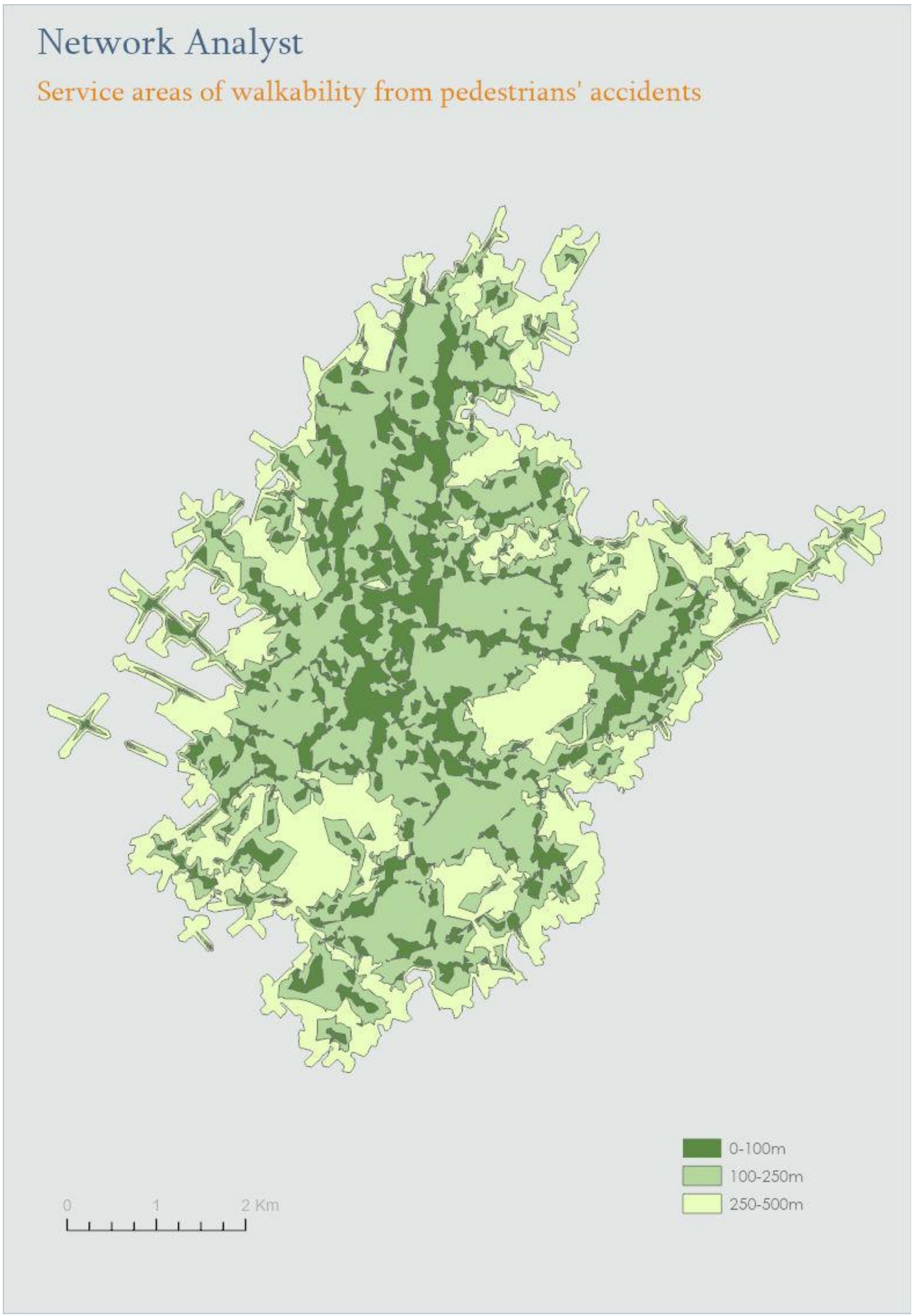


Figure 4.41: Network analyst generation of service areas within 100m, 250m, 500m walking distance

4.4. The build environment Influence

To determine the build environment parameters that might correlate with the locations where most of the pedestrian accidents occur, three-point data sets were used. The first one was the data set with the points of interest, which is consisted of different types of land use. This was a large dataset downloaded from open street maps and obtained information on the locations and types of land use that are spotted in the city of Athens. After studying the dataset, it was decided that not all of the land uses could be linked with the accidents. Previous research was mainly studying the link between entertainment type of land uses or retail etc. Uses like benches or atm were decided to be of no impact; therefore, they were exempted from the analysis (figure 4.42).

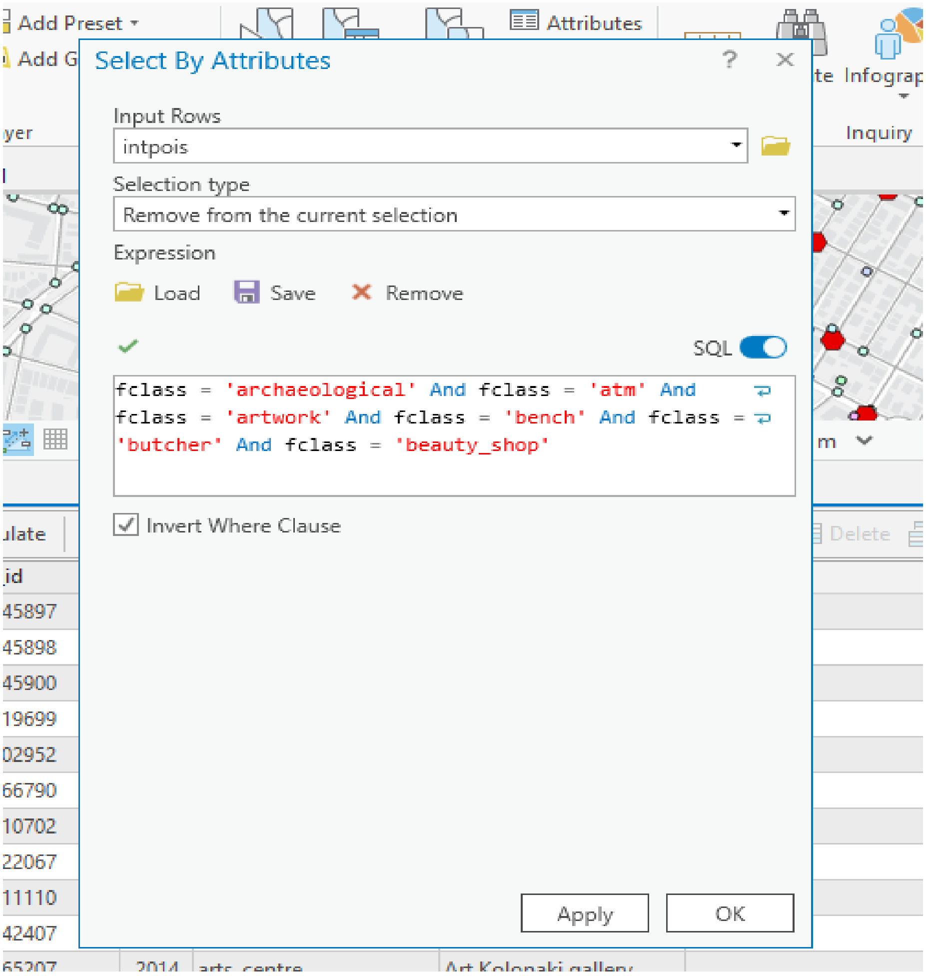


Figure 4.42: Points of interest database clearance

The points of interest related to alcohol consumption and educational institutes used in the analysis are shown in the chart of figure 4.43. Furthermore, traffic and transportation-related data (figure 4.44 and 4.45) were considered to be important for this type of analysis, and they were analysed along with the points of interest. Groups of points that share the same characteristics were formed as they were considered to have the same impact.

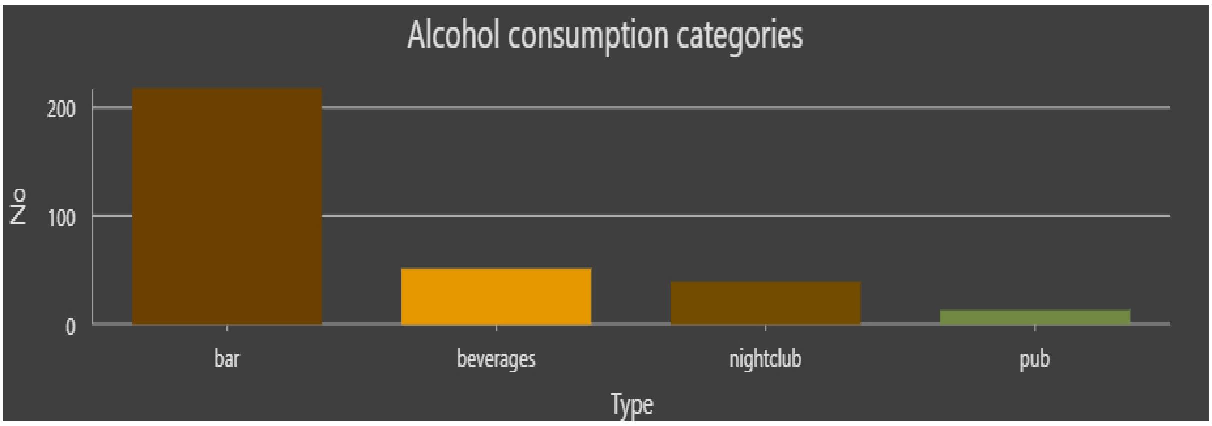


Figure 4.43: Chart of Alcohol consumption related points of interest

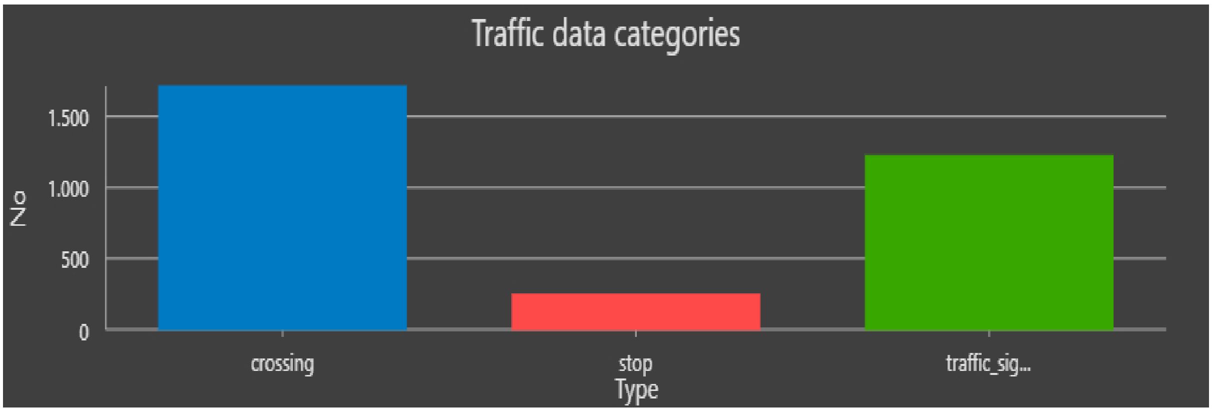


Figure 4.44: Chart of traffic data

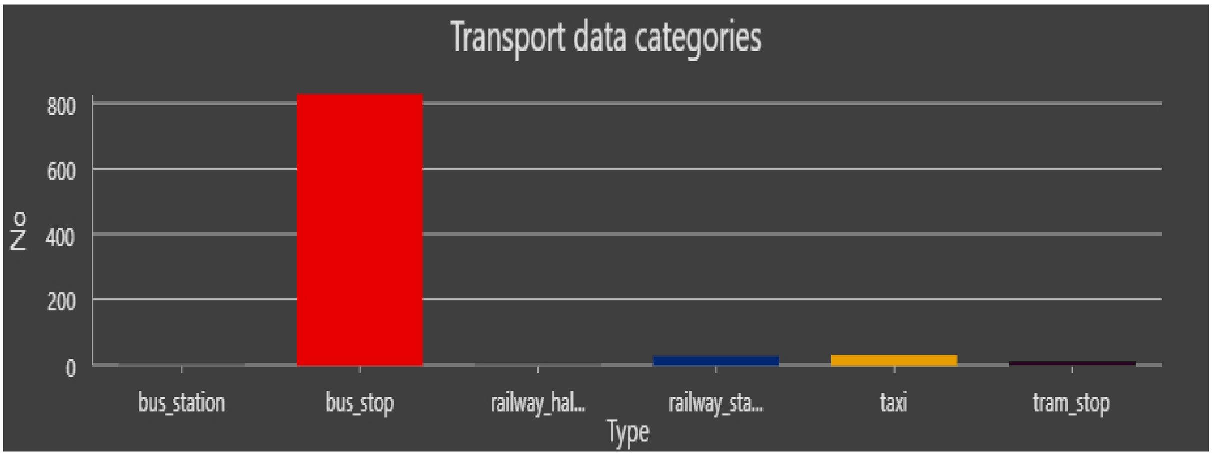


Figure 4.45: Chart of transportation-related data

Figure 4.46 shows the points of interest and the transport data points, which were labelled and symbolised to better visualise the results.

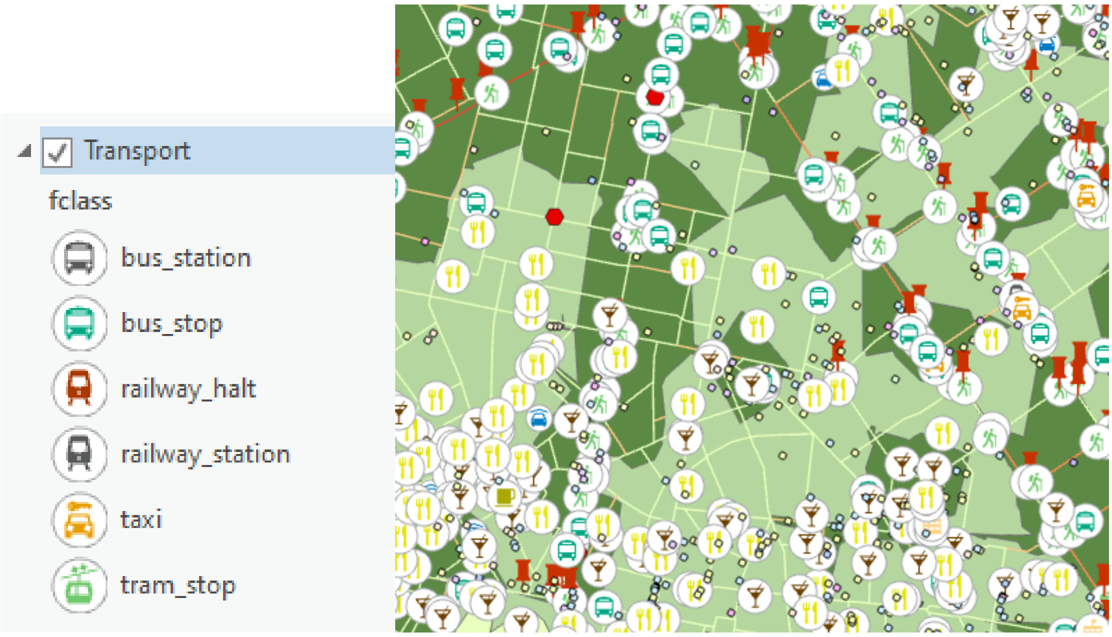


Figure 4.46: Symbology application on points of interest

As mentioned above, the network analysis was conducted in three different zones regarding the distance from the pedestrian accidents' locations. The points of interest were firstly measured in each zone (table 4.4).

Table 4.3: Points of interest in the 3 zones of analysis

Distance from accident location (m)	No of educational institutes	No of Traffic points	No of alcohol consumption locations	No of Transport points	Sum	%
Zone 1 (0-100)	23	1675	81	393	2172	48,1
Zone 2 (100-250)	47	1228	206	365	1846	40,9
Zone 3 (250-500)	39	255	29	108	431	9,6
(>500)	10	27	1	23	61	1,4
Sum	**119**	**3185**	**317**	**889**	**4510**	**100**

Additionally, the elliptical distributions of the four categories of the points of interest were calculated and visualized on the maps of figures 4.47, 4.48, 4.49 and 4.50. The differences in the distributions of each feature per category are shown as follows. Universities, colleges and tram stations have the smallest distributions and the mean centre of tram stations is located in the southern area of the city.

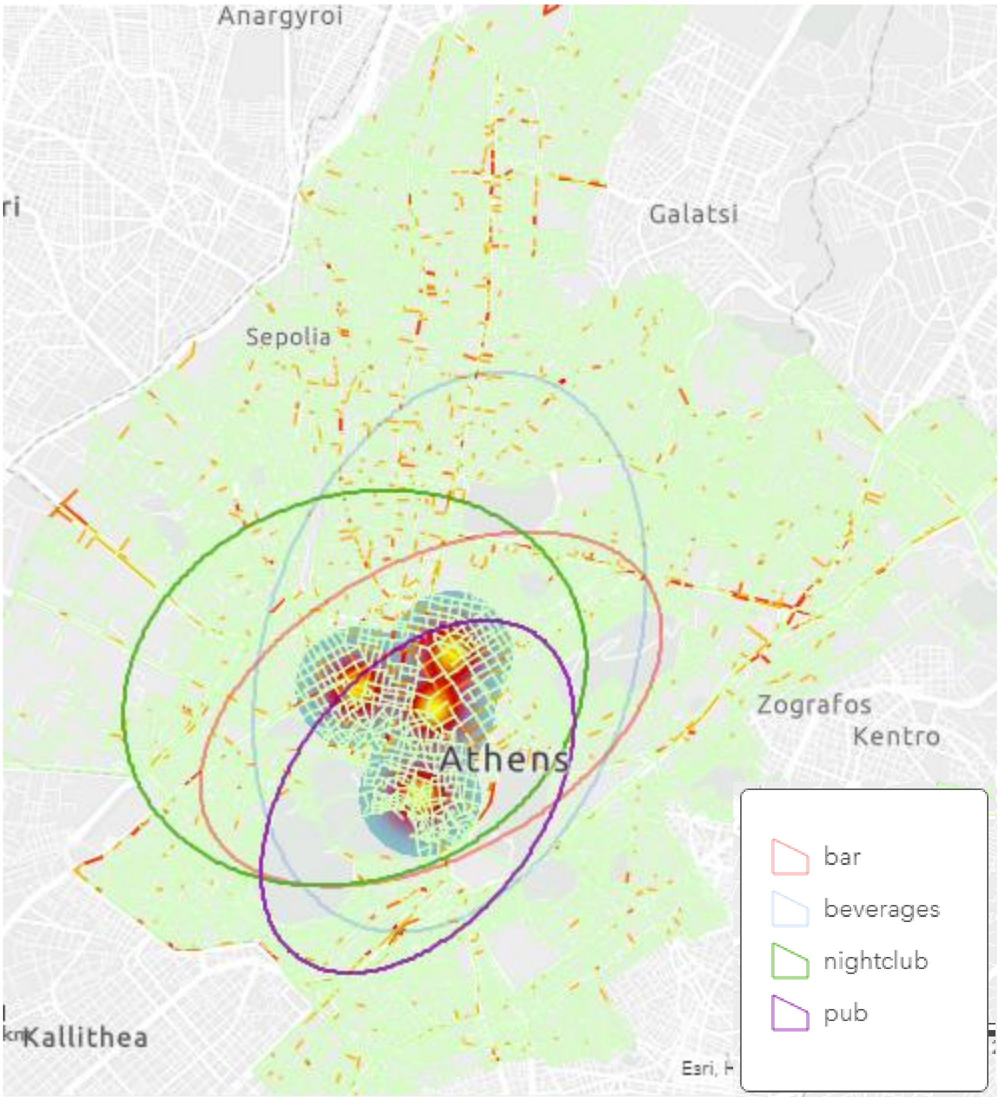


Figure 4.47: Distribution of Alcohol consumption locations

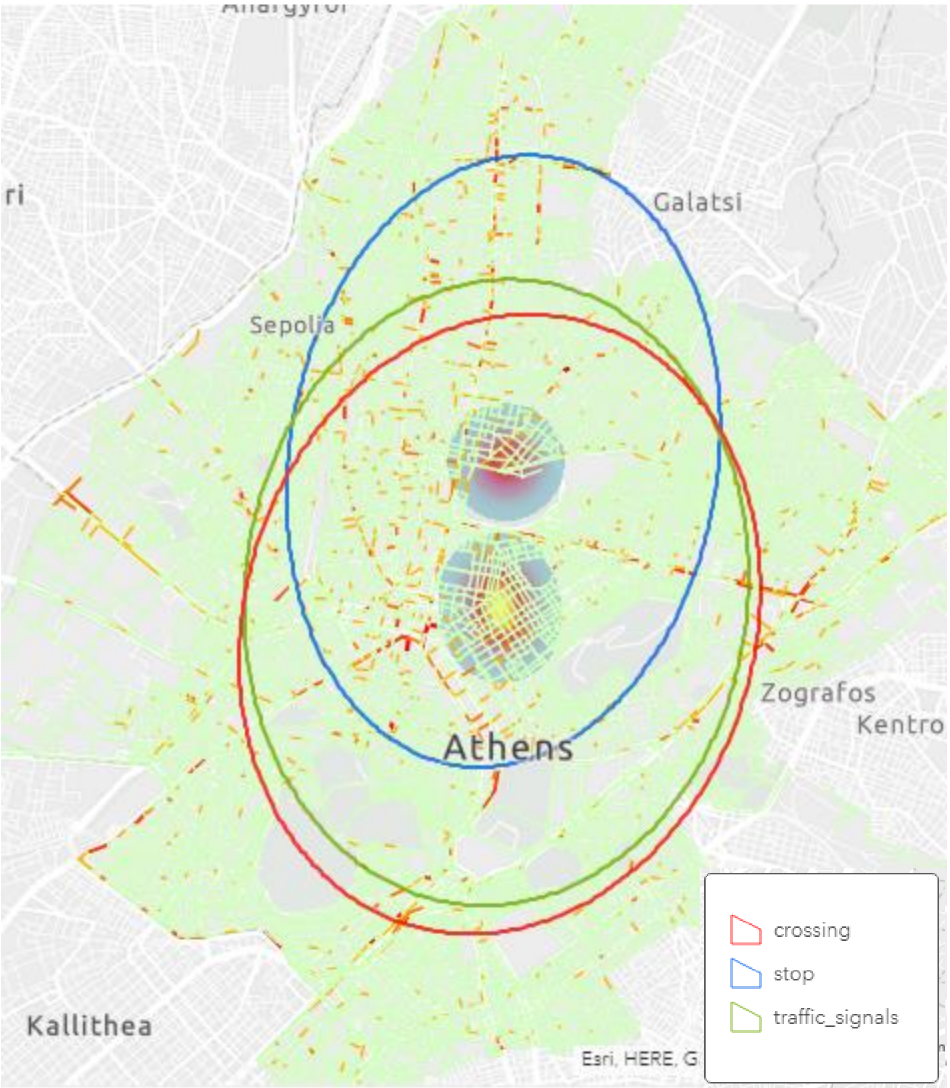


Figure 4.48: Distribution of traffic-related data

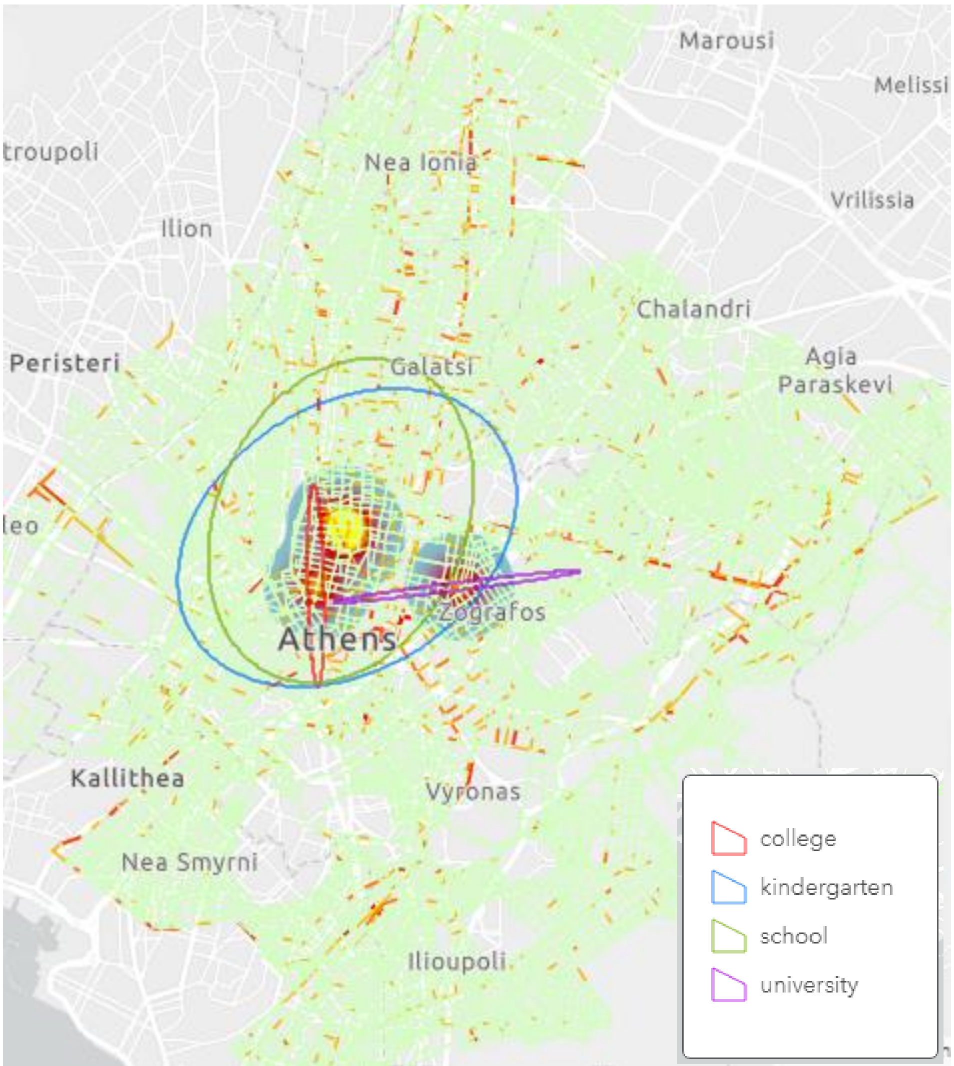


Figure 4.49: Distribution of schools

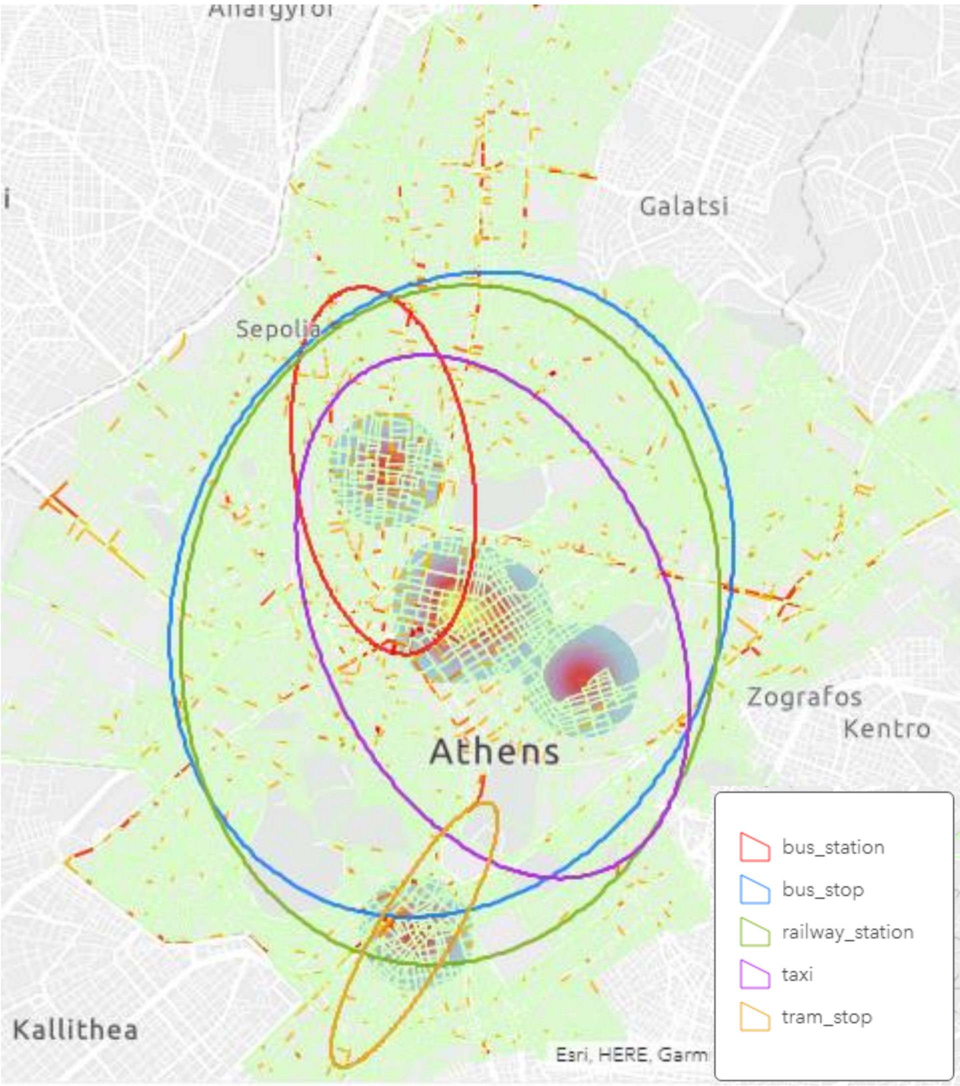


Figure 4.50: Distribution of transport-related data

Bivariate maps were composed to determine whether there is a correlation between the points of interest groups, as presented above, and the pedestrian accidents. Figure 4.50 displays the relation between pedestrian accidents and the locations of alcohol serving shops (bars, pubs, nightclubs, beverages). The relation is displayed through the colour schemes. The yellow colour scheme refers to pedestrian accidents and the blue one to the alcohol consumption services. The other colours show the correlation of the two groups with the red colour showing the areas of high alcohol consumption and high-density accidents. In order to compose the map, both features were normalised per area. The areas that show a correlation between the highest rates in accidents and alcohol consumption are spotted mostly in the city centre, through Syggrou Avenue, Peiraios street near Rouf near Ampelokoipoi and on the North Near Patisia.

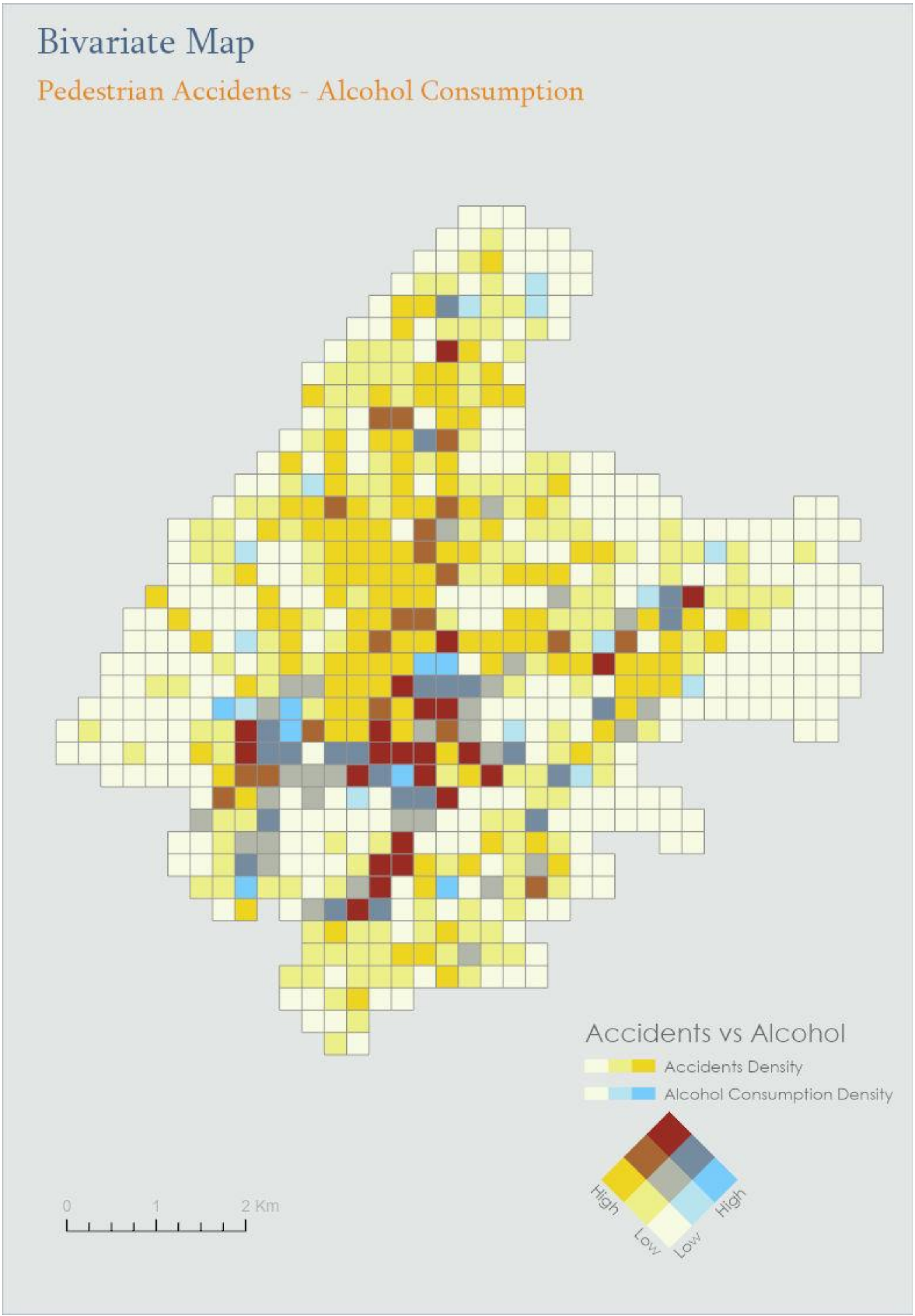


Figure 4.51: Bivariate map of the relation between pedestrian accidents and alcohol consumption

Figure 4.51 displays the bivariate map of the relation between pedestrian accidents and means of transport. It shows that the accidents relate to the means of transport mostly in the city centre but shows high connection through all the city as well.

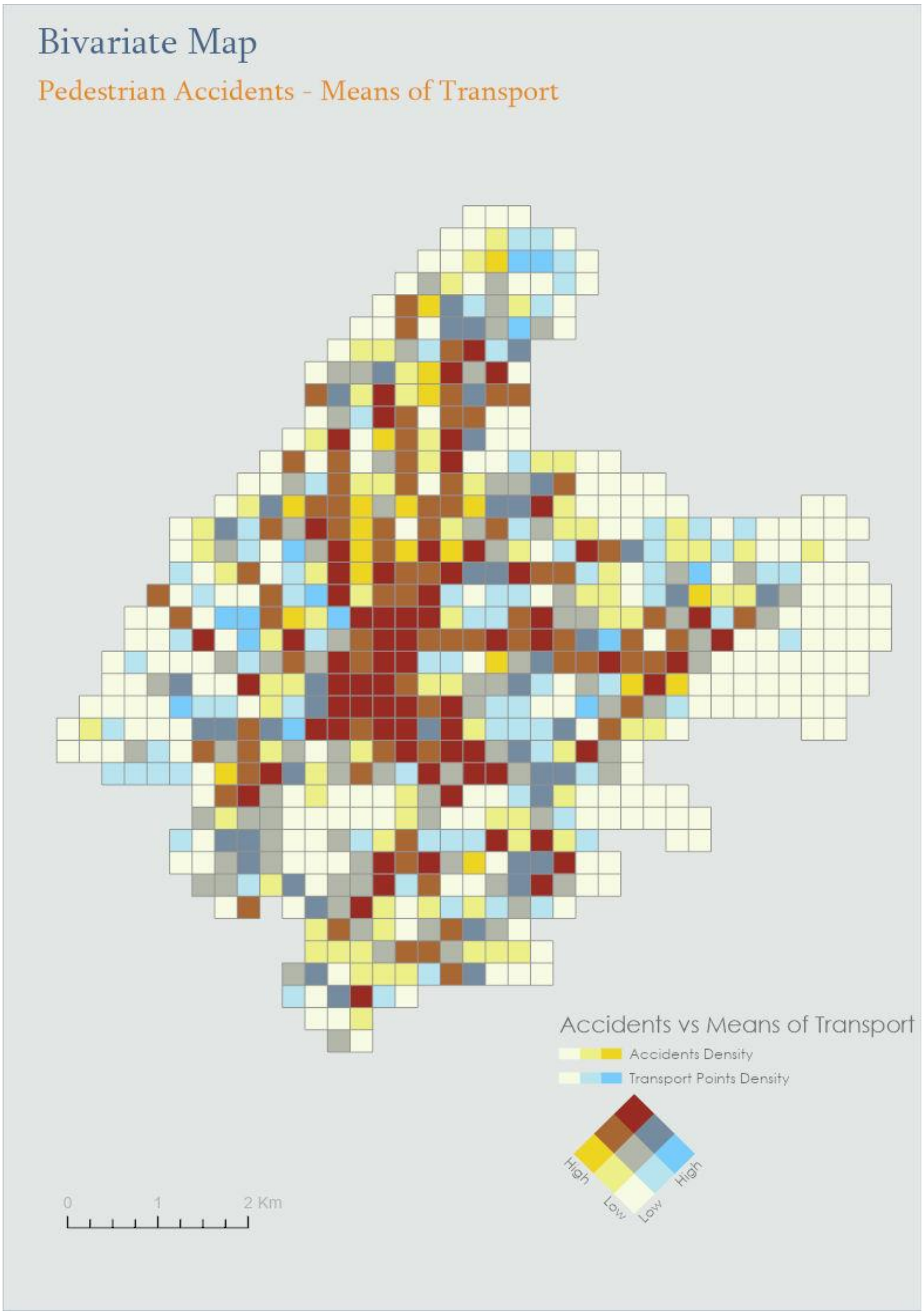


Figure 4.52: Bivariate map of the relation between pedestrian accidents and public means of transport

Figure 4.52, with the map of the correlation between pedestrian accidents and traffic-related points, indicates higher values of connection between the two features in most of the areas, and especially in the city centre.

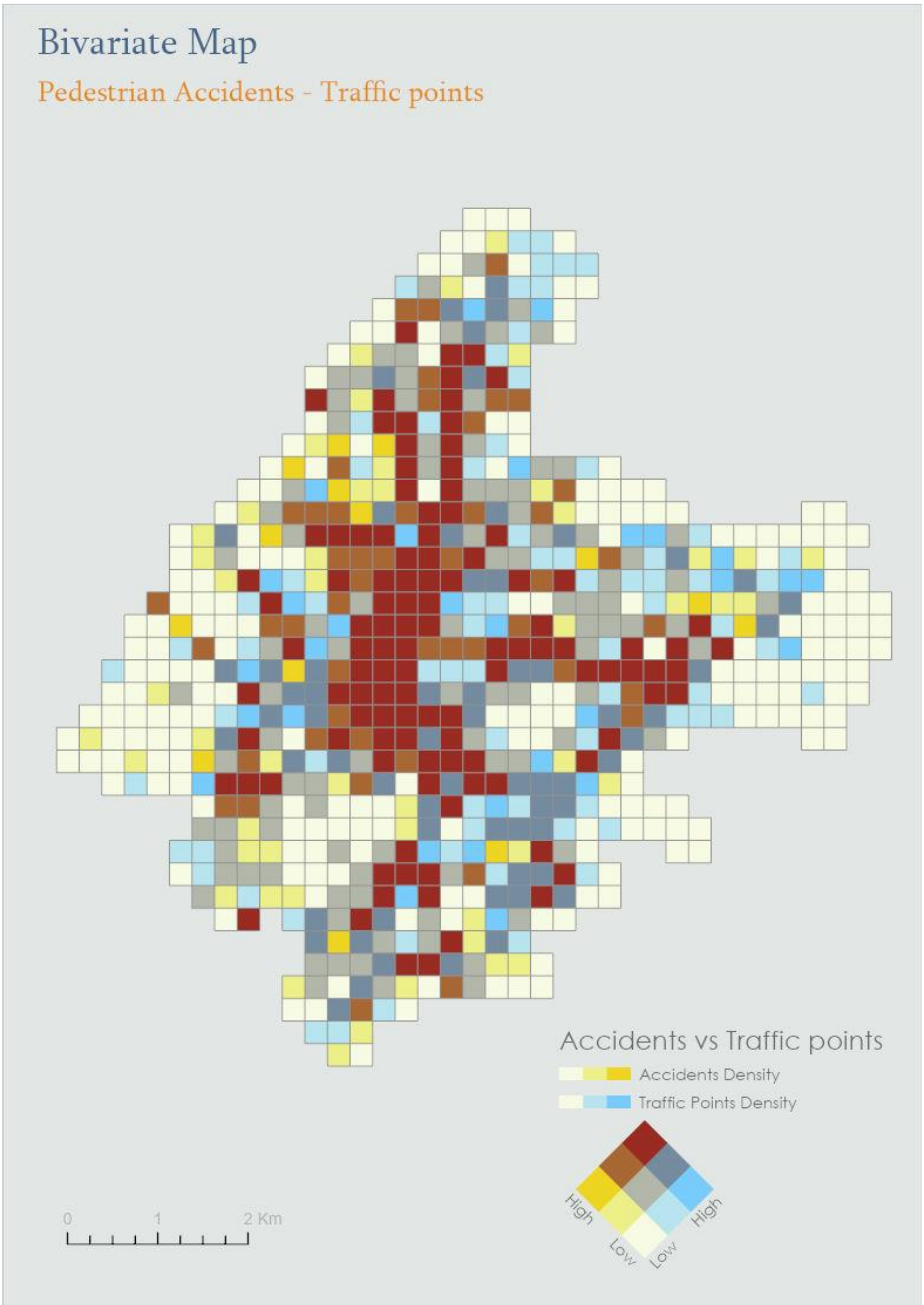


Figure 4.53: Bivariate map of the relation between pedestrian accidents and traffic related points

The map of figure 4.53 indicates a few locations with a high correlation between pedestrian accidents and educational institutes.

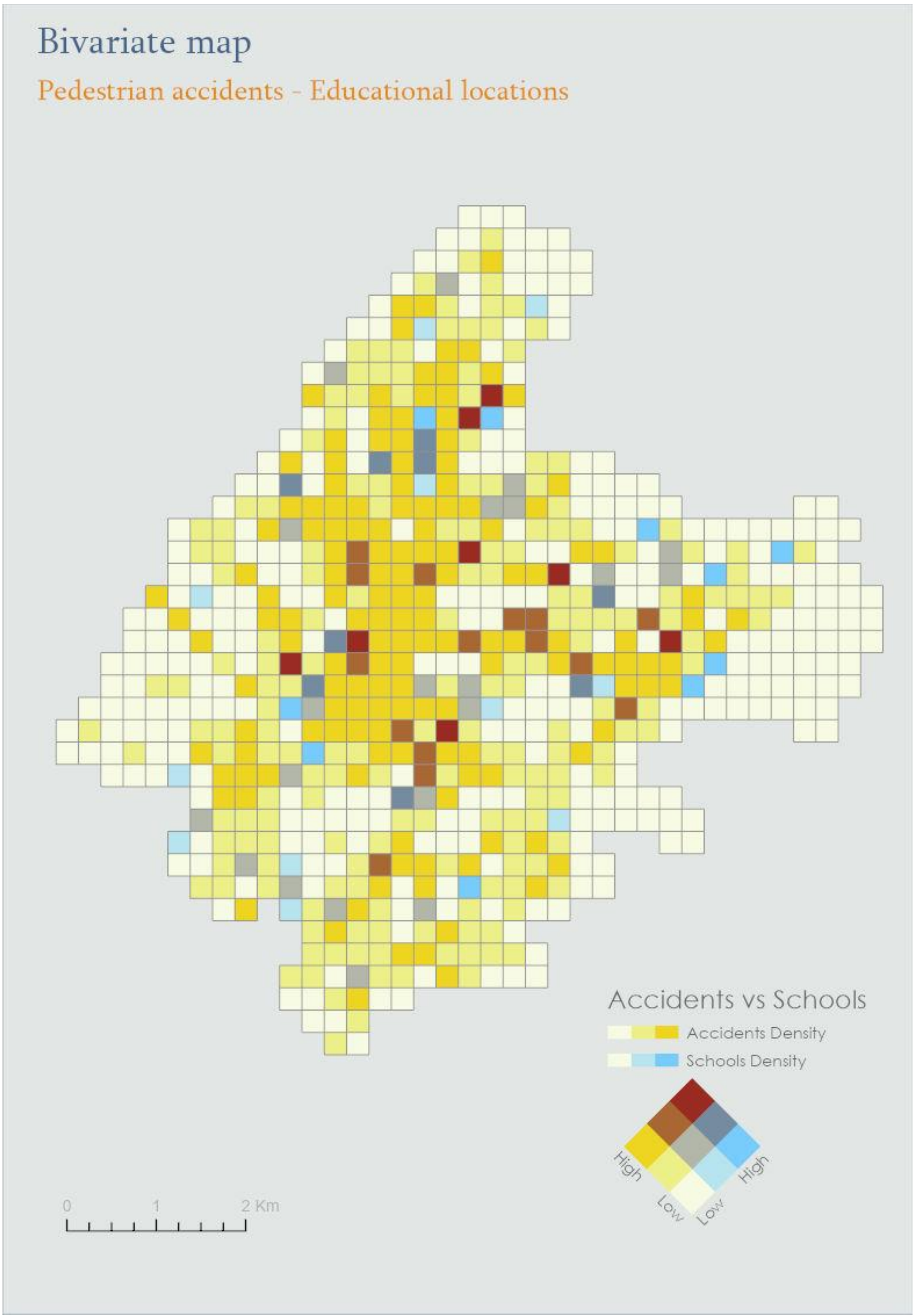


Figure 4.54: Bivariate map of the relation between pedestrian accidents and Educational Institutes

Figures 4.55 and 4.56 show the results of Bivariate Local Moran I analysis for alcohol consumption location points and traffic points concerning pedestrian accidents. As far as alcohol consumption points are concerned the high-high areas mostly concentrated in the city centre while low alcohol consumption and low in accidents areas are mostly found in the northern parts.

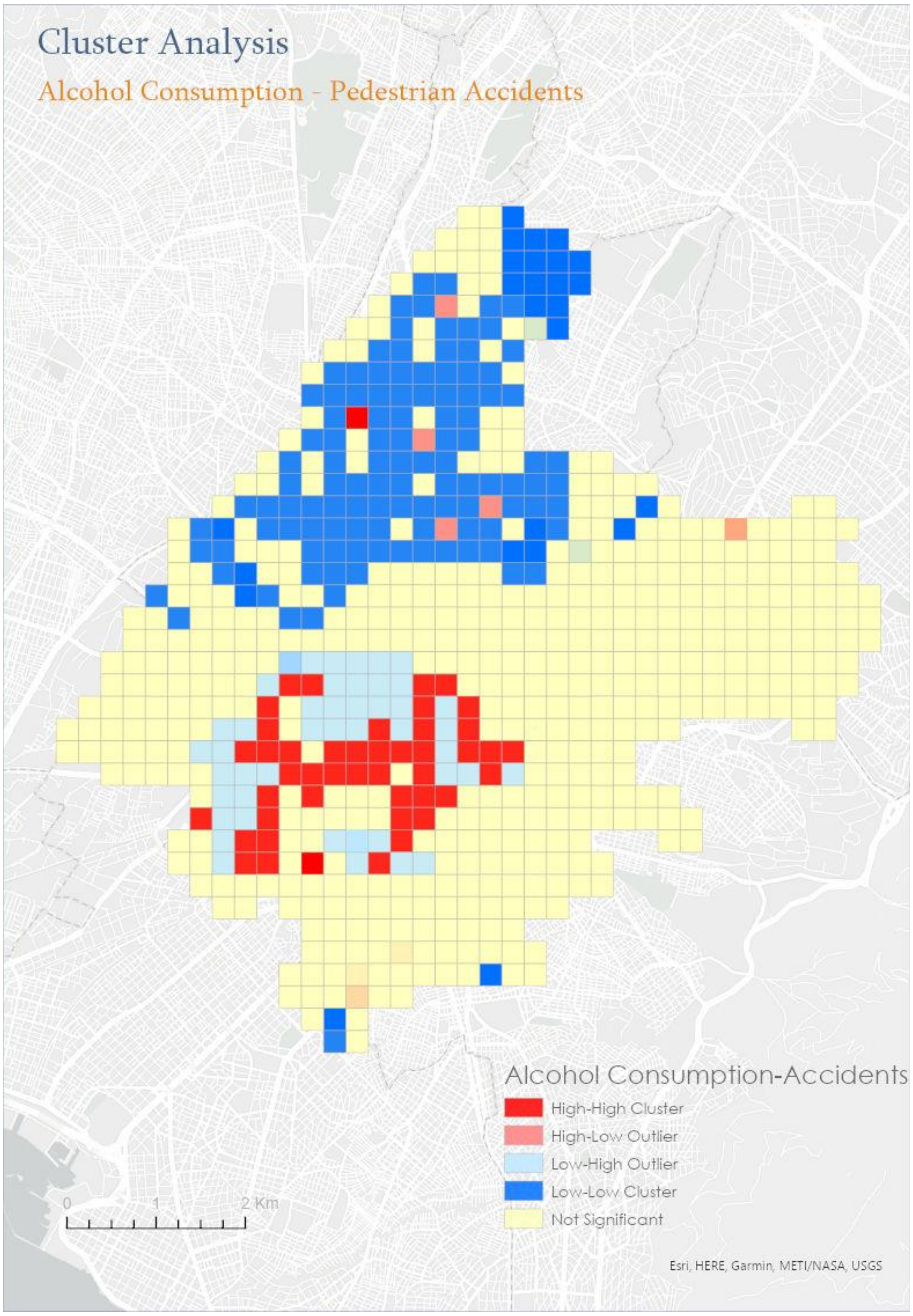


Figure 4.55: Outliers (Alcohol consumption points – pedestrian accidents)

As per traffic points, the high-high areas are found in the east and south-east areas and some northern parts of the city.

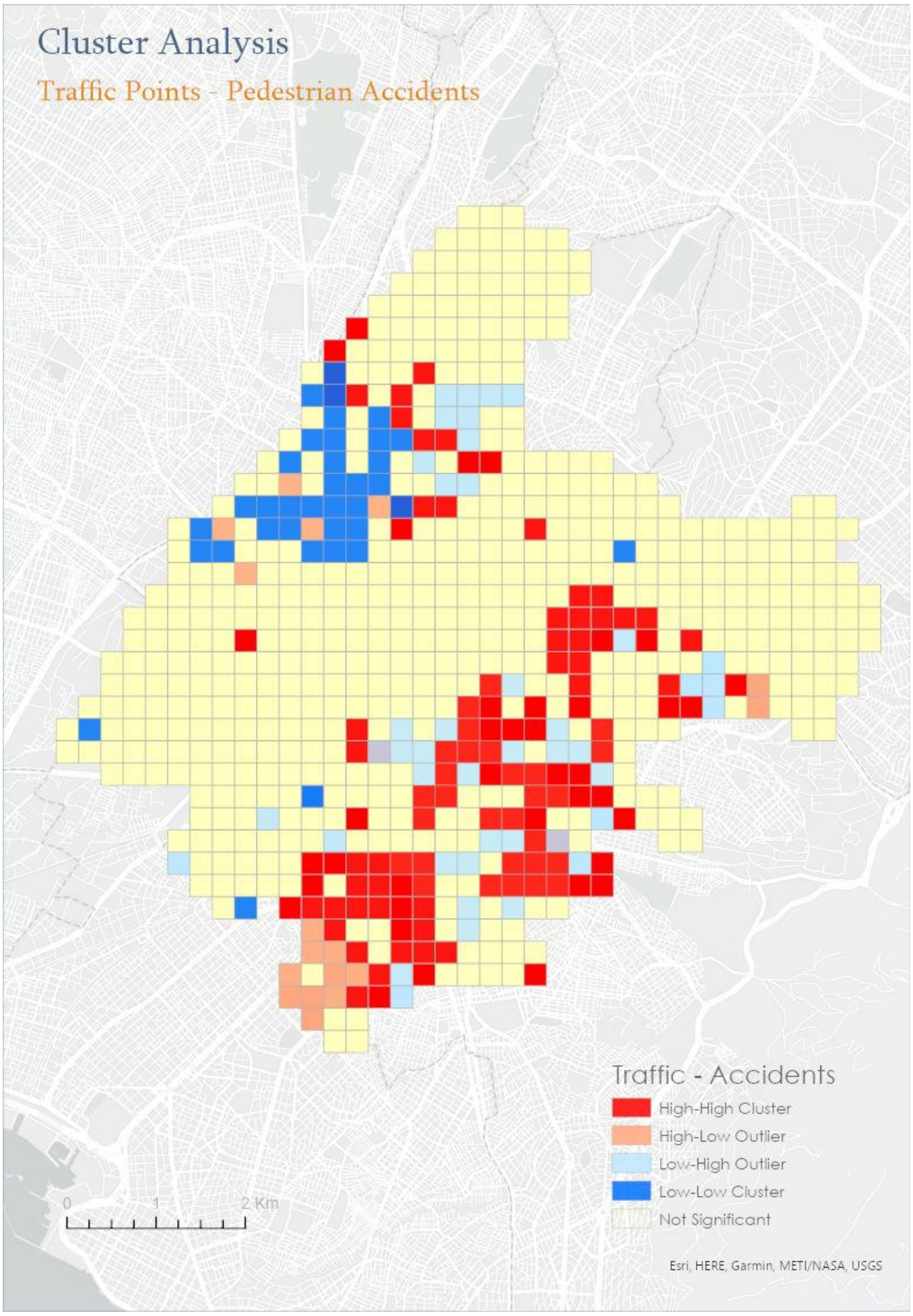


Figure 4.56: Outliers (Traffic points – Pedestrian accidents)

Geographically Weighted Regression was performed to determine the local variations of the spatial distributions of the correlations found in the previous steps. Figures 4.57-4.60 show the results for each point category.

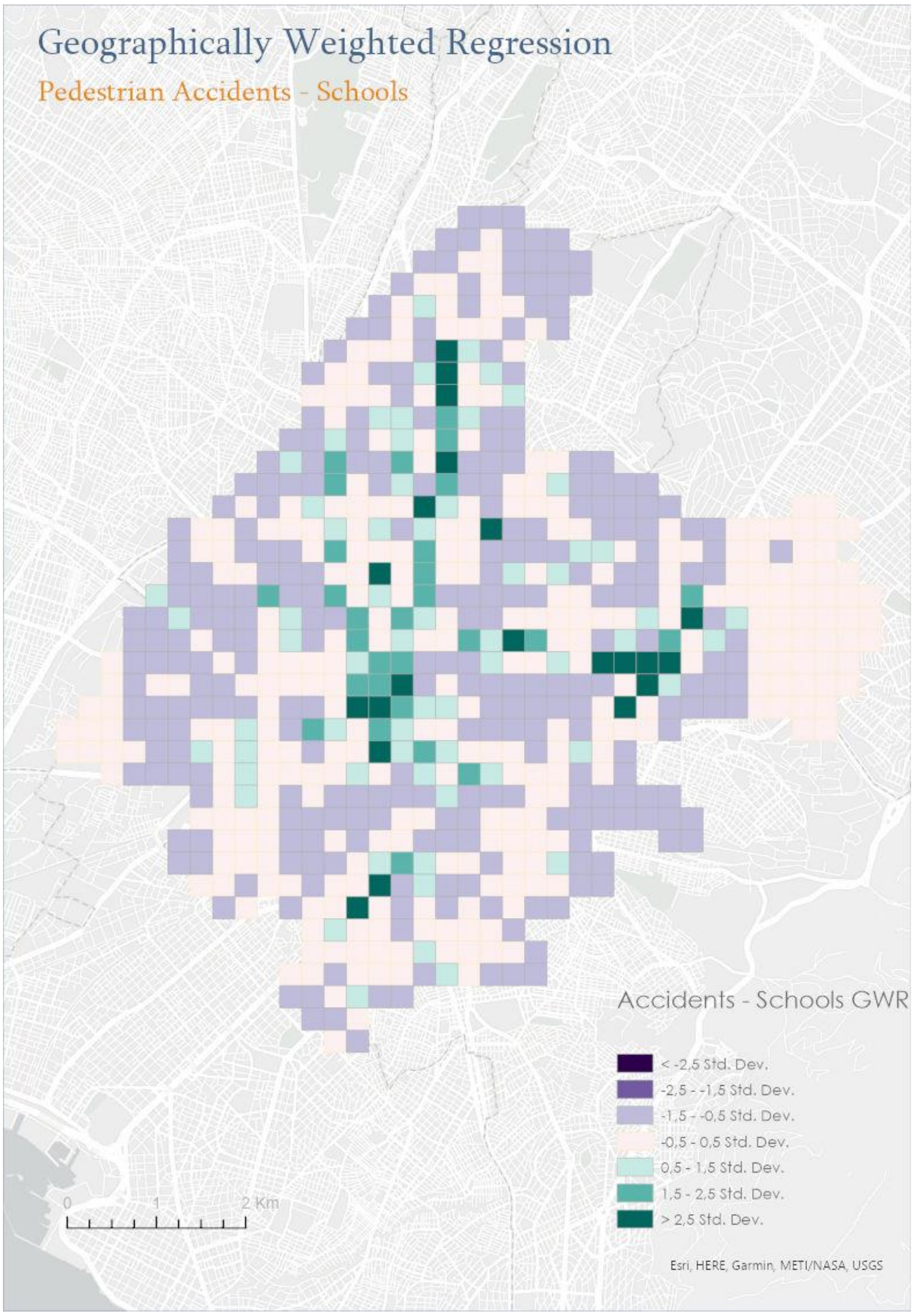


Figure 4.57: GWR (Pedestrian accidents – Schools)

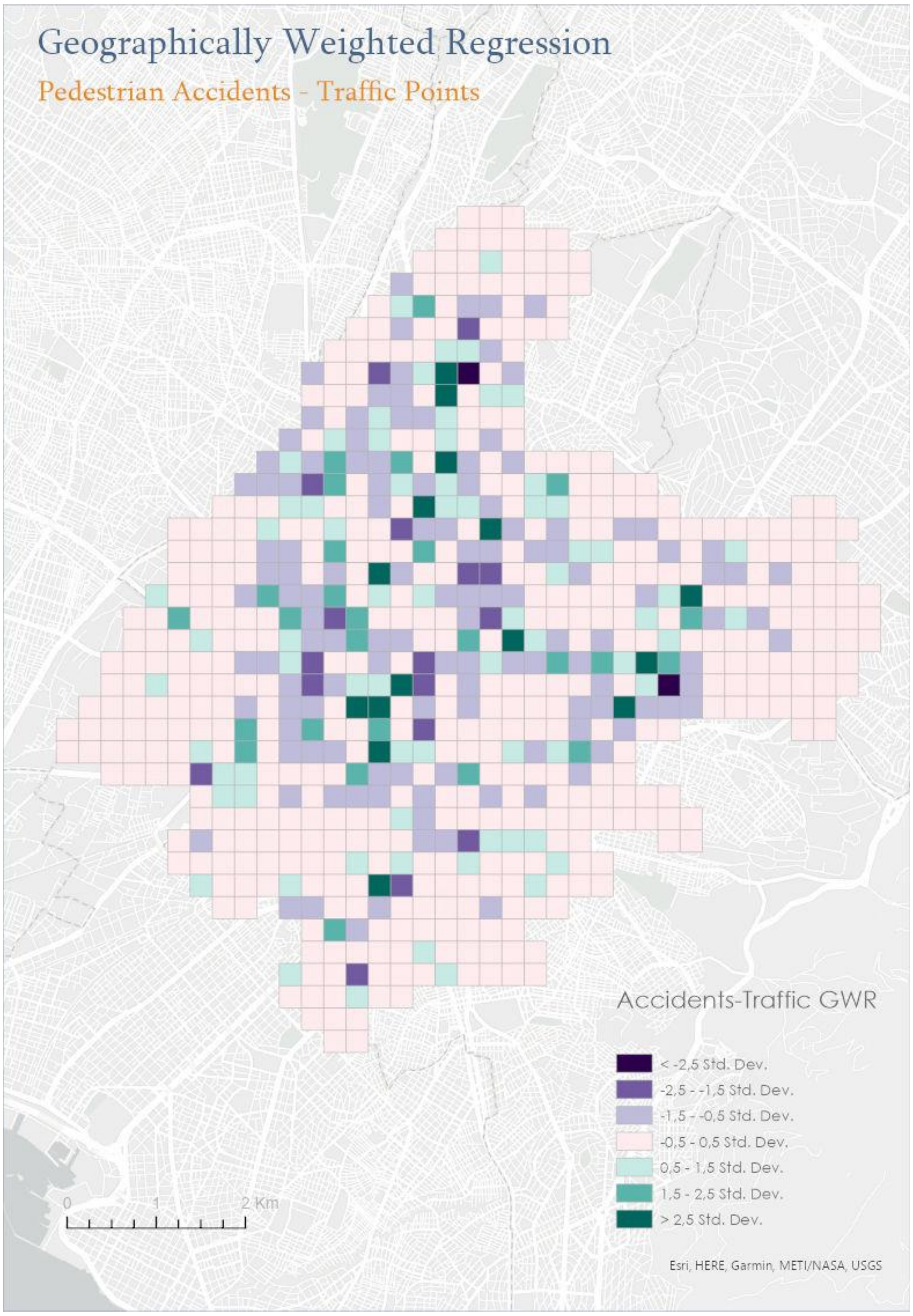


Figure 4.58: GWR (Pedestrian accidents – Traffic related points)

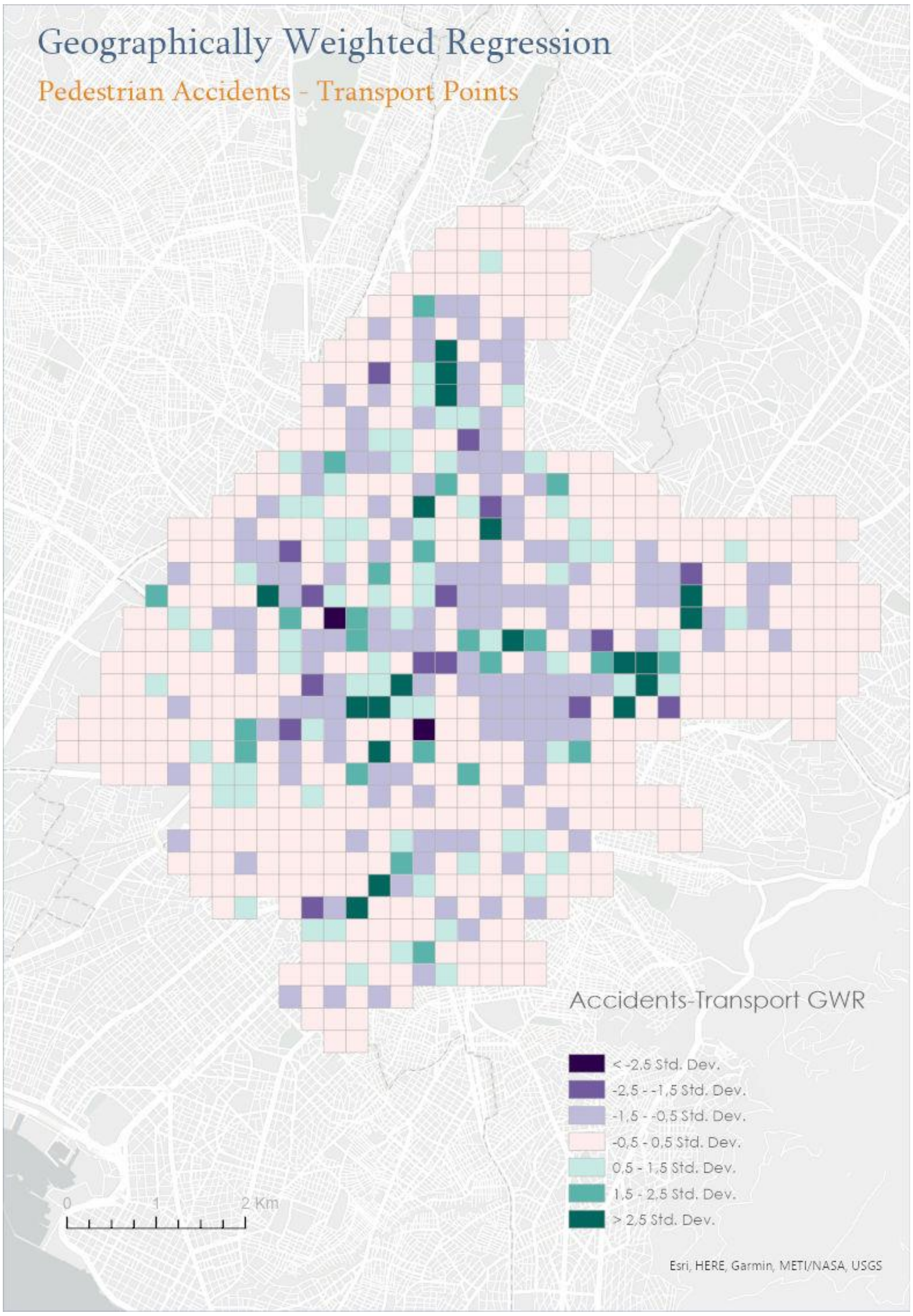


Figure 4.59: GWR (Pedestrian accidents – Transport related points)

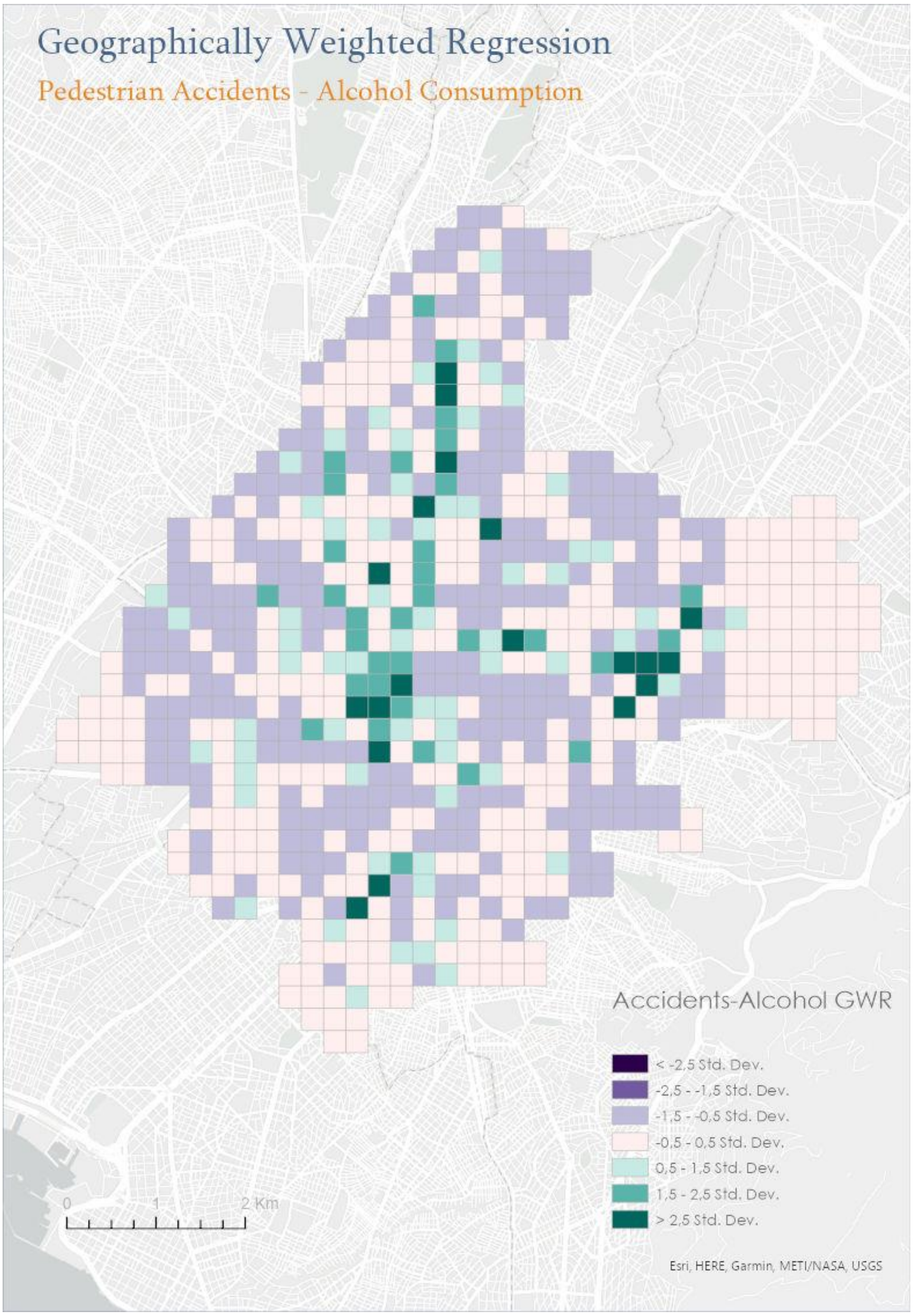


Figure 4.60: GWR (Pedestrian accidents – Alcohol consumption related points)

Moreover, ten locations with the highest density of accidents were observed from google maps and street view, to better understand the conditions of the built environment where the accidents took place. The locations were chosen from the segmentation and the space cube analysis because these analyses showed the high in accident density location and their pattern through time. Thus, eight of the areas were characterized as persistent and two of them, in the Northern parts of the city, were characterised as intensifying.

Problematic areas

- *Athinas Street*

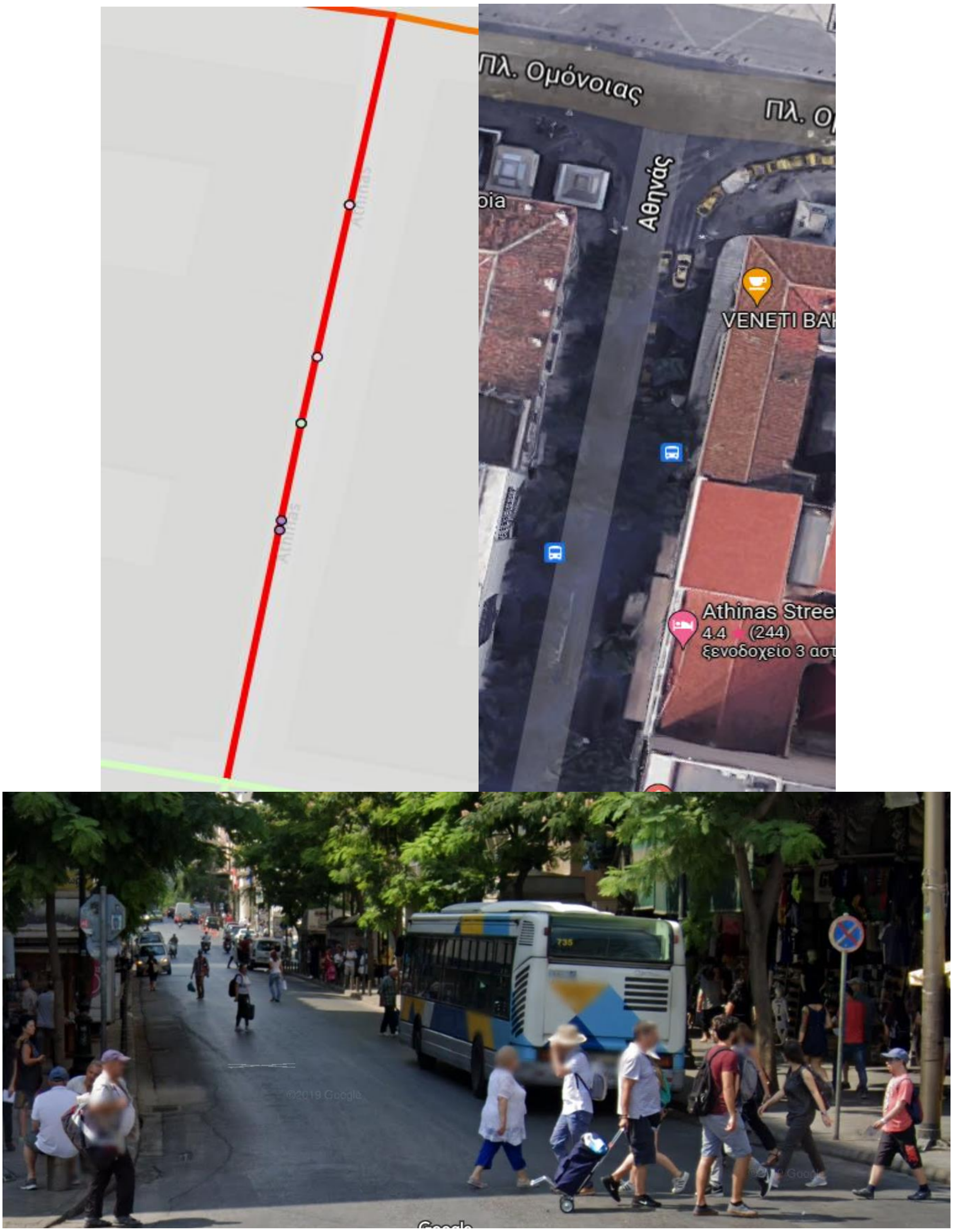


Figure 4.61: Athinas Street next to Omonia square (source: google maps, https://goo.gl/maps/75Zw52DETkx98J4U9)

Athinas street appears to be a persistent location concentrating a lot of accidents through the years. Pedestrians are spotted jaywalking through the segments of the street while there are several crossings. Jaywalking is commonly used in Greece in general, while the area is known for being overcrowded during daily hours. Athinas is a two-laned – two directions street, located near many shops and the city market.

➢ P. Tsaldari - Peiraios Street (near Omonia square)

Figure 4.62: P. Tsaldari - Peiraios Street near Omonia Square (source: google maps, https://goo.gl/maps/JPvYPMa5Pdvuqh7p7)

Peiraios Street near Omonia Square is a very busy segment with pedestrians and vehicles through all the hours of the day. It is a two-laned one direction street at its part near Omonia square surrounded by many shops. It was found to be a persistent hotspot for accidents through the years. Traffic signals and crossings are located at the segment. Jaywalking is very much spotted.

- 28th Oktovriou

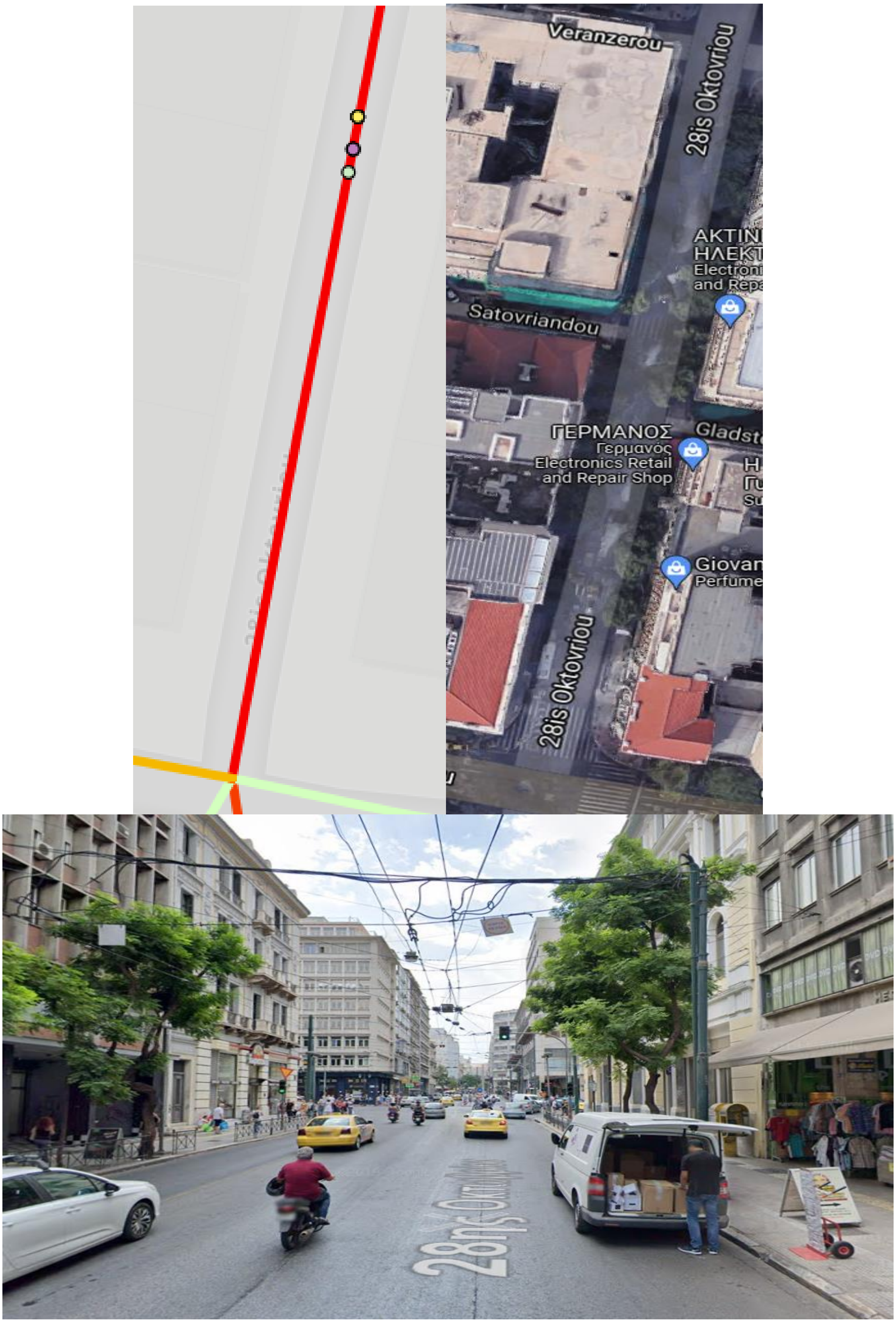


Figure 4.63: 28is Oktovriou and Gladstonos (source: google maps https://goo.gl/maps/X7AwccNSTgSKQg5Z7)

28is Oktovriou is a 3+1 lanes street with one traffic signal at the junction with El Venizelou street and crossings. Jaywalking in many parts of the street is often.

➢ P. Tsadari - Peiraios Street (near Kerameikos)

Figure 4.64: P. Tsaldari - Peiraios street near Kerameikos (source: google mpas, https://goo.gl/maps/Cp1BUB73s4yHXKe76)

Peiraios street near Keramikos with 2+2 direction lanes with traffic lights and crossings,

- Vasilissis Amalias Avenue (near Syntagma square)

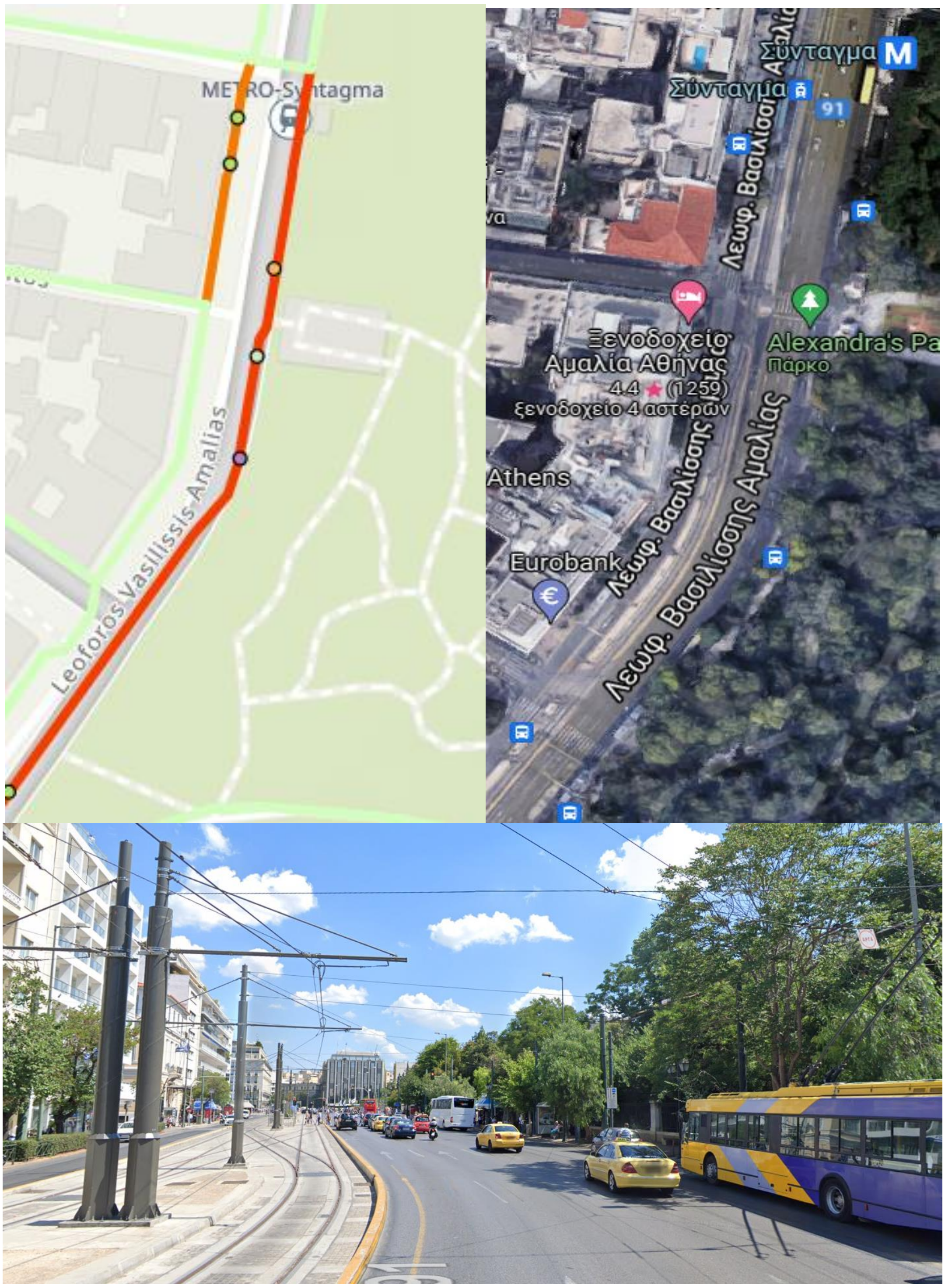


Figure 4.65: Vasilissis Amalias Avenue near Syntagma square (source: google maps, https://goo.gl/maps/L8jZcH7BEdGSgBUo7)

Vasilissis Amalias Avenue near Syntagma square has 4+1 lanes separated by the tram line. There are crossings and traffic lights through its segments.

- Aleksandras Avenue and Vasilissis Sofias Avenue junction

Figure 4.66: Aleksandras Avenue and Vasilissis Sofias Avenue junction (source: google maps, https://goo.gl/maps/8nZ8pXM1KNQ2s7p76)

Aleksandras Avenue and Vasilissis Sofias junction and nearby segments. Spotted as a persisting hotspot. Crossings and traffic lights are located mostly at the junction while jaywalking is often spotted in many parts of the segments (figure 4.66). Both Avenues have two directions separated by an islet.

- Aleksandras Avenue

Figure 4.67: Aleksandras Avenue (source: google maps, https://goo.gl/maps/vxzAtJgtAS6G69yP8)

Alseksandras Avenue is, in general, spotted to have many hotspots at different parts. A persisting hotspot is located near the Apostolos Nikolaidis Stadium. At the specific location, there are 3+3 lines on the Avenue separated by an islet. Traffic lights and crossings are located at the junctions.

➢ 28is Oktovriou and Galatsiou Avenue

Figure 4.68: 28is Oktovriou and Galatsiou Avenue (source: google maps, https://goo.gl/maps/KokR3PFn8ijS53Em9)

28is Oktovriou and Galatsiou Avenue junction is located in the northern part of the city of Athens. This is also found to be a persisting location for pedestrian accidents. There are traffic lights and pedestrian crossings at the location while the area is mostly residential with very few shops.

➢ Kypselis street near Kypselis Square

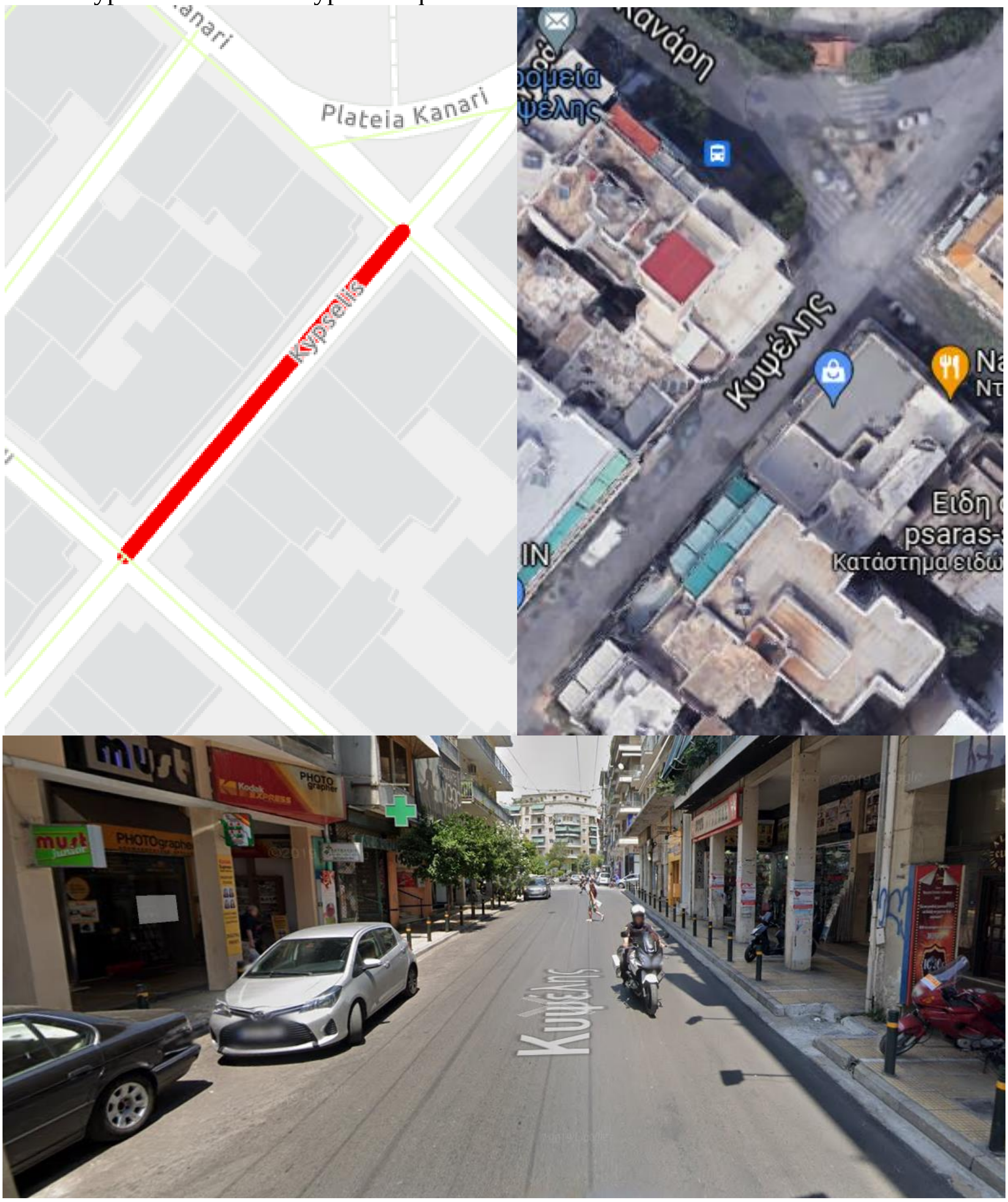


Figure 4.69: Kypselis Street (source: google maps, https://goo.gl/maps/vQJ99hPZi8dhtwYRA)

Kypselis street near Kypselis square appeared to be an intensifying hotspot. The area has a high percentage of the population, while it has a mix of land uses. Crossings are located near the Square while jaywalking is a permanent situation.

➢ Syggrou Avenue

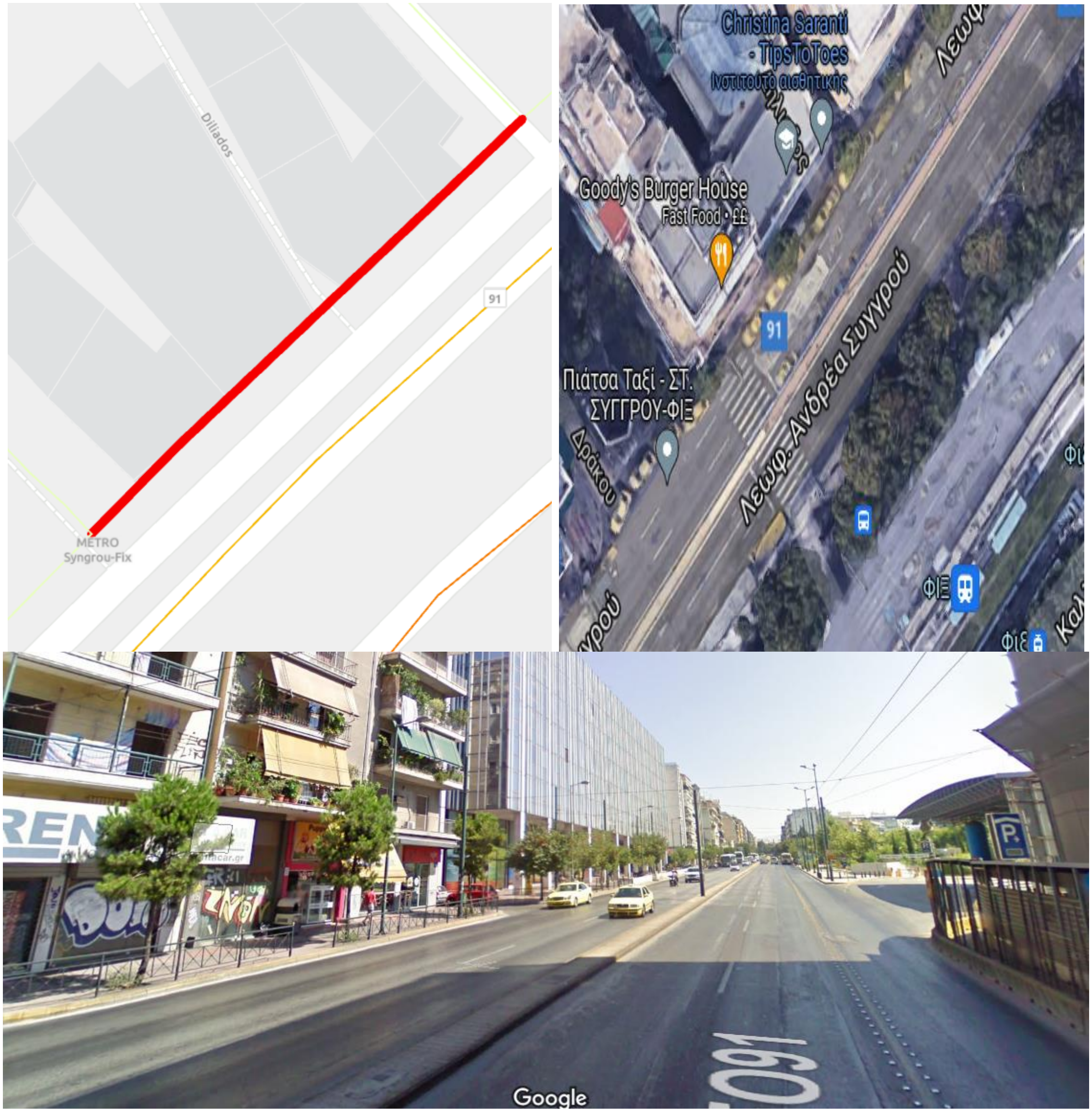


Figure 4.70: Syggrou Avenue (source: google maps, https://goo.gl/maps/dC7FZSX69H7f6Sbi6)

Finally, Syggrou Avenue near Syggrou-Fix metro station is an intensifying hotspot. The Avenue has 3+3 lanes and both traffic lights and crossings are located in the segment.
It is suggested a more specific study on these areas to capture specific patterns on the movement of both pedestrians and vehicles to apply measures for the improvement of the situation. Vehicles tend to be the dominants of the network and there is a mentality of not giving the priority to the pedestrians. On the other hand, jaywalking is another mentality that causes delays on the network and even incidents. Additionally, other factors like the lighting conditions or speed factors should be taken into consideration.

4.5. Dashboard creation

Road accidents are part of emergency events in the area, and they need to be addressed promptly not only for the safety of the persons involved but also due to the problems they cause in the network traffic. The emergency events in each area are treated separately from the services in charge, as they lack a common operating system that works in real-time. The dashboard built for this study can be a basic dashboard for a real-time operating picture that shows the incidents in Athens.

In order to proceed with the dashboard creation, it is firstly needed to decide the features that will be displayed. In this case, the features displayed will be the pedestrian accidents, the police stations in the city of Athens, the fire stations and the hospitals. All the features should be displayed in a web map; therefore, they were all shared as web layers in ArcGIS Online (figure (4.70)

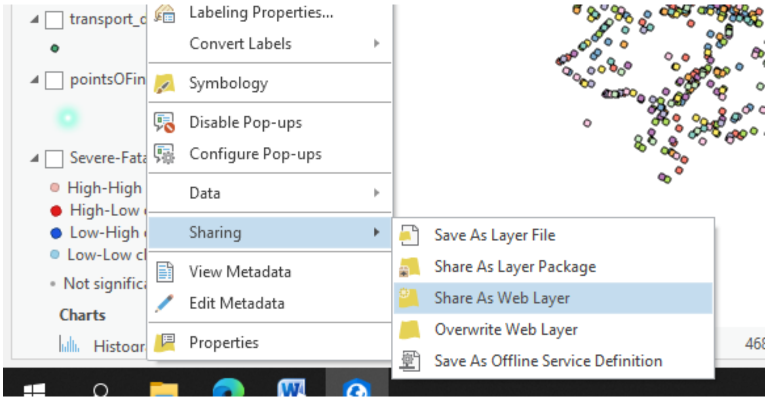


Figure 4.71: Sharing the data as a web layer

To use ArcGIS online, an account should be created and use a trial version of it or purchase a license. After being published in ArcGIS Online, the layers can be added to a Web Map. Along with the mentioned layers, the World Traffic Service layer was added as well. This layer is a real-time traffic layer that is informed with real-time traffic data, which are important for calculating the time needed by an ambulance, for example, to arrive at the accident's location (figure 4.71).

In addition, some configurations must be made in each layer about the attributes that will be displayed during the selection of the features and that the time refreshing intervals of each layer are set (figure 4.72). Time refreshing intervals can be set only for the Traffic layer, as the other layers, in this case, are static. For the Traffic layer, the intervals were set every 5minutes.

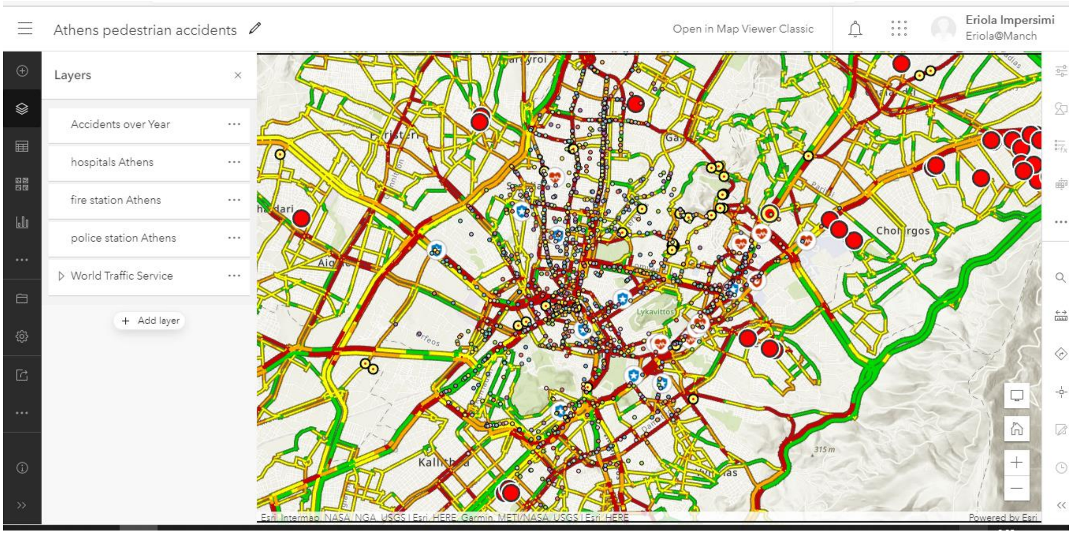


Figure 4.72: Online map composition on ArcGIS Online

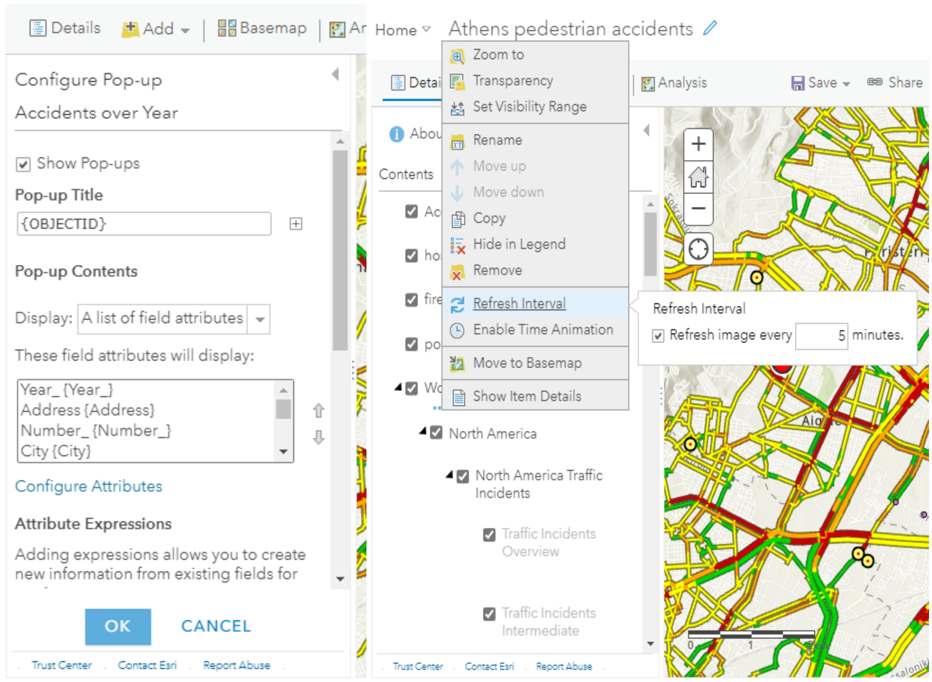


Figure 4.73: Map configurations and settings

When all the configurations and settings are completed, the map can be shared as a web app and specifically a dashboard. Sharing options change depending on whether someone is interested in sharing only with his organisation, or everyone.

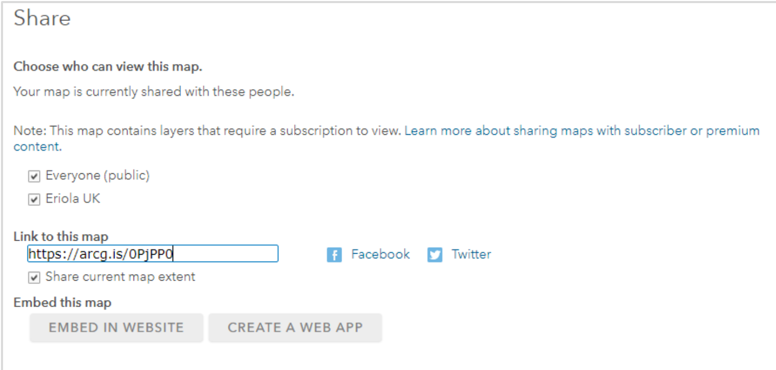


Figure 4.74: Sharing the online map as a dashboard

Once the dashboard is created, many settings are available to create its style. There are options on layer visibility, Basemap switching, searching options, theme changing, adding charts or indicators, etc. After trying among different options the dashboard of figure 4.20 was created, which shows the basic map in the centre with all the previously described layers, a serial and pie chart on the left and an indicator of the number of accidents since 2008. The serial chart shows the number of accidents per year, while the pie chart shows the percentages of the severity categories. The dashboard is published and publicly shared in the link below.

[Athens pedestrian accidents (arcgis.com)]

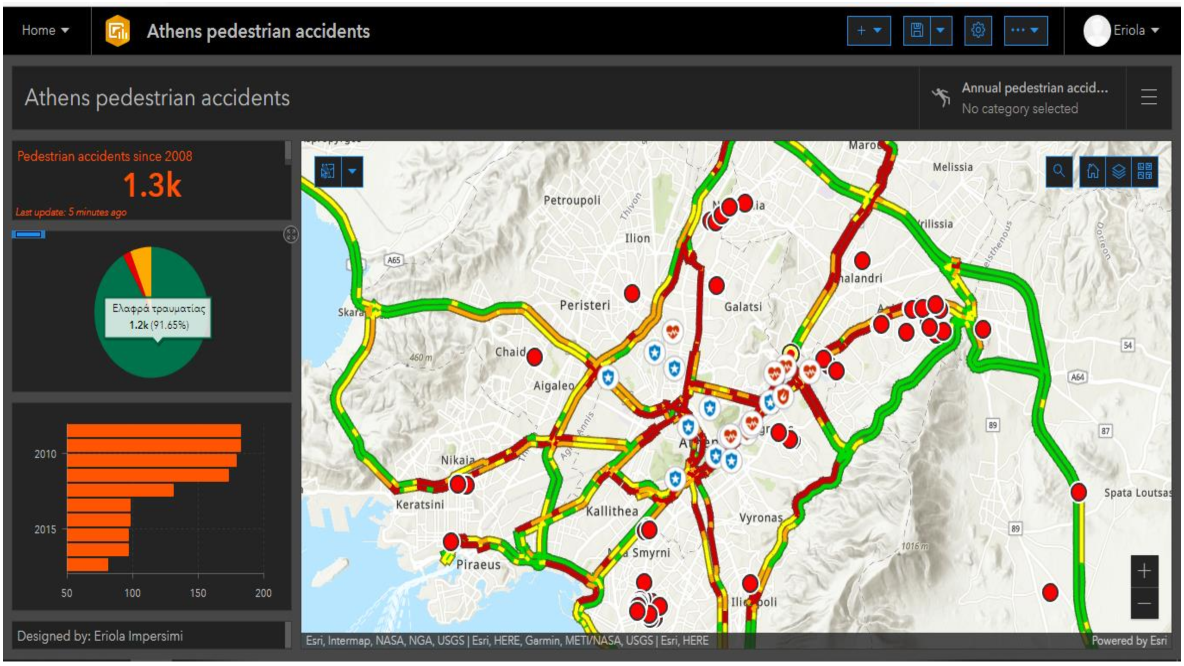


Figure 4.75: Athens pedestrian casualties' dashboard

5. CONCLUSIONS

Pedestrians are the more vulnerable users of the traffic network and show a very high percentage of road accidents and fatalities. When it comes to road safety, many factors should be considered that might affect road users in general, but as pedestrians are involved in the biggest percentage of car accidents that occur, an attempt to lower pedestrian accidents number would have a greater impact on road accidents in general. This thesis aims in analysing pedestrian accident data that occurred during the period of 2008-2017 in the city of Athens and attempt to identify correlations between the built environment and the accidents. The Spatio-temporal analysis took place in a GIS environment with the use of different methodologies and tools. The results showed different patterns of accidents within the city. Additionally, the hotspots where most pedestrian accidents occur through the years were identified and spatial correlation techniques were used to specify any connection between the accidents and the surrounding environment.

5.1. Analysis Conclusions

Spatial analysis results identified a high density of pedestrian accidents in Athens city centre. More specifically, the accidents' density was compared to the population in each local community of Athens. It was found that the 1st local community has the highest density of pedestrian accidents with a low population density, while the 6th local community has the highest rates in accidents and population density as well. The pedestrian accidents, therefore, may be related to the percentage of the population in an area.

Subsequently, with the use of Space-time cube analysis, the patterns of the areas where more accidents took place were determined. The results indicate that there are 16 persistent hotspots in the city, with 13 of them gathered around the road segments of the city centre and areas the area of Exarcheia. In addition, there are three intensifying and two consecutive hotspots in the northern part of the city. In addition, network analysis took place in network segments where the accidents were projected to spot the road segments with the highest number of pedestrian accidents through the years, determining the hotspots of the road network. Road segments with a high number of collisions per year are spotted in the city centre near Omonia square, especially on roads Peiraios-Stadiou-28is Oktovriou and Athinas, near Ampelokipoi around the junction Alexandras Avenue – Vasilissis Sofias Avenue and through all the Vassilissis Sofias Avenue, at Vasilissis Amalias Avenue, Suggrou Avenue as well as 28is Oktovriou road. This analysis identified some road segments on the south part of Athens high in accidents as well, which were not shown by the space-time cube analysis. When used along with hourly/daily data, segment analysis can create different maps for the days of the week to see the traffic and crashes difference daily.

Furthermore, Kernel density was also used to verify the high-density areas where the most accidents occurred through the years. This analysis showed two very high-density areas, one in central Athens and one in the East around the area of Ampelokipoi. Four high-density areas were spotted around the city centre, on the East, around Alexandras Avenue segments and on the segments connecting the city centre and North Athens. Kernel density was also performed separately for the groups of accidents of slight severity and fatal/serious severity, respectively. The results from the first groups showed similar results with the whole sample as this group has the highest percentage in the sample. The fatal/serious severity group showed high-density areas through Aleksandras Avenue and Vasilissis Sofias Avenue, Near Omonia square and Northern of the city near the area of Galatsi.

Bivariate maps were composed to determine whether there is a connection between the pedestrian accidents and the different groups of interest points that were examined. As for alcohol consumption services, the result showed that the areas with a correlation of the highest rates in accidents and alcohol consumption are spotted mostly in the city centre, through Syggrou Avenue, Peiraios street near Rouf near Ampelokoipoi and on the North near Patisia. The traffic-related points and the means of transport were identified as having a high correlation with the accidents in most areas of the city and particularly in the city centre. Finally, educational institutions show a low correlation with the accidents and the areas that show a high correlation are dispersed.

Lastly, ten hotspot areas, eight persistent and two intensifying were examined to better understand the conditions at each of them. Traffic and transportation points were found in the surrounding areas and a mix of land uses in general. Field research is suggested for a more specific study to capture patterns in the movement of both pedestrians and vehicles and to apply measures for the improvement of the situation. There is a mentality on behalf of the drivers to not give priority to pedestrians. On the other hand, jaywalking is another mentality that causes delays on the network and even incidents. Therefore, apart from the land use and other factors of the built environment, a socio-economic study should be taken into consideration, to suggest improvements with educational programs as well as accident prevention measures. To conclude, there is also a need to consider more drastic changes in the built environment and solutions that provide paths or areas more walking-friendly, with more greenery, shades and wider pedestrian paths.

5.2. Future Research

This thesis studied a sample of 1318 pedestrian accidents through the period 2008 – 2017. The data available was only limited to information about the year that the accident occurred, their exact location, the severity and the persons involved. However, this information is not enough for detailed studies. Further analysis might be conducted with data that can specify the day of the week and the hour of the day that the accidents occurred. These might provide more information and have a different correlation with the built environment. Accidents that happen during night hours usually tend to be more related to alcohol consumption, whereas morning hour accidents can be more related to school hours or business hours. In addition, data about the education level or age groups of the population in a specific area might also be related to traffic accidents. In this case, different types of methodologies and analyses can be used as well. Furthermore, with regards to the specific problematic locations that this study identified, a further and more detailed analysis can be performed to track the reasons that these areas tend to be constantly connected with accidents. Suggestions should be made for concrete solutions, as interventions to the built environment might lead to reductions in pedestrian injuries. Additionally, educational programs along with prevention measures should be considered as a solution on this occasion.

Moreover, it would be interesting to analyse a wider area of the Attika region to determine the patterns in different built environments. Likewise, the same study can be conducted on a country scale to identify the differences between the cities of Greece. Pedestrian accidents are complex and multifaceted due to the various factors that can cause them. Therefore, other studies can additionally consider factors like network traffic load and traffic jams in specific locations, the road type, pedestrian and driver condition, as well as vehicle condition, lighting conditions, weather conditions, etc., and identify the patterns of pedestrians' maneuvers on comparison to other cities.

Lastly, the dashboard that was developed during this study contains information about the pedestrian accident's locations and hotspots and locations of services such as hospitals and police stations of the city. A real-time layer of the World Traffic Service is provided as well, and its information is rendered every 5minutes. This dashboard can be the basis of a dashboard that provides real-time data from incidents through the city and the available services that can respond each time and occasion. The World Traffic service layer would be of help for the calculation of the time needed to respond to each incident. It would also be helpful on the reports of each incident and the determination of the services needed to the response.

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