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TEMPORAL AND SPATIAL ANALYSIS OF TRAFFIC ACCIDENTS: THE CASE OF BURSA CITY

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Abstract

The increase in the population over time in Turkey causes an increase in the number of vehicles. In turn, the increase in the number of vehicles hampers urban transportation. Congested traffic results in a number of problems. One of these problems is traffic accidents. In this study, traffic accidents which occurred in five central districts of Bursa were investigated in terms of temporal, spatial and temporal-spatial. The reason for choosing the central districts is that traffic accidents occur more intensively in these districts than other districts. The data used in this study include traffic accident data from 2015 to 2020 and land use data for 2018. ArcGIS 10.8 and ArcGIS Pro 2.5 version were used to identify analyses and findings. In ArcGIS version 10.8 point density, collect events, Anselin Local Moran I, Emerging Hot Spot Analysis and 2D Visualize Space Time Cube tools were used. Time, day, month, season and year information were included in the time related analyzes of traffic accidents. Land use, district, neighborhood and highway data were used in spatial analysis. As a result of this study, findings were determined under three subtitles. These were temporal, spatial and temporal-spatial titles. When examined in terms of time, only the year 2020 drew attention out of five years. This resulted from pandemics. Seasonally, the lowest number of traffic accidents were recorded in winter while the highest were recorded in summer. When the distribution of traffic accidents according to highways was examined under the title of spatial, the most occurred on Ankara Street. Finally, it was determined that traffic accidents, which were examined under the title of temporal-spatial, were intense in residential areas and industrial areas.

Keywords: Traffic Accident, Temporal Analysis, Spatial Analysis, Hotspots Analysis, Bursa

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INTRODUCTION

Transport; it is defined as the transportation or transmission of people, animals, goods or information from one place to another. At the same time, transportation is a service which enables people or loads to be transported from one point to another by using different means of transportation in time and space (Yardımcıoğlu, 2013; Tümertekin, 1987).

Although the transportation sector has different forms today, the most preferred mode of transportation by people is road transportation. The preference of road transportation vehicles, particularly in freight and passenger transportation, increases the traffic density and causes traffic accidents.

Traffic accidents have caused and continue to cause deaths, injuries and financial losses throughout the world, particularly in underdeveloped and developing countries. Traffic accidents cause in 1,35 million deaths and 20 to 50 million non-fatal injuries worldwide (WHO, 2018; UNECE, 2020). Regarding the spots where the traffic accidents occurred, it is observed that traffic accidents occur intensively at spots where the population is dense and daily activities are high (Levine, Kim & Nitz, 1995; Levine & Landis, 1989).

According to the report published by the World Health Organization in 2018, the death rate due to traffic accidents is 18,2 per 100.000 people. Regional distributions of death rates are also given in the same report (Figure 1) (WHO, 2018). Approximately 90% of traffic accidents occur in underdeveloped and developing countries. At the same time, 54% of the vehicles are located in these countries (Nitin & Adnan, 2006).

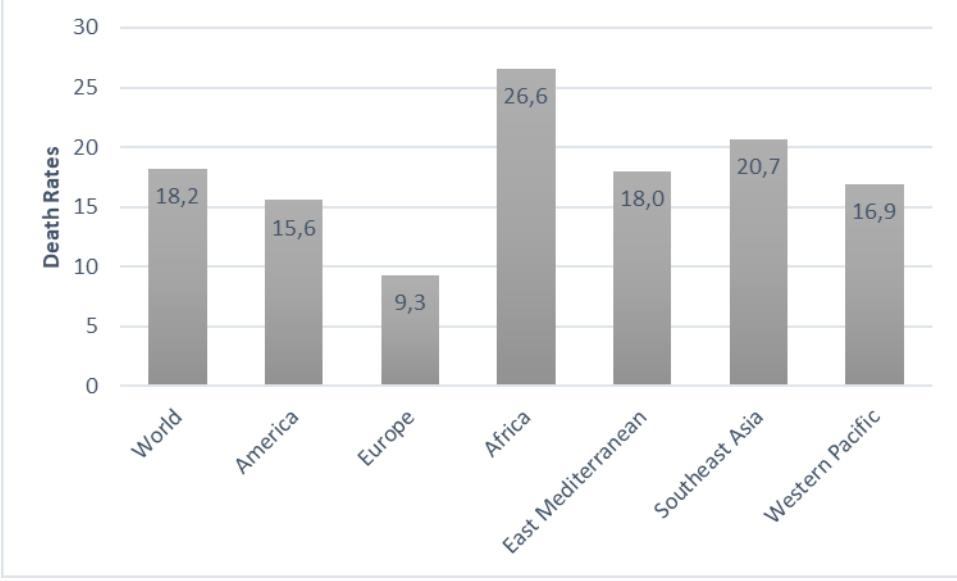


Figure 1: Traffic Accident Mortality Rates Per 100,000 People

Traffic accidents have negative consequences not only in terms of health but also in economic terms. The annual cost of traffic accidents is approximately 518 billion dollars worldwide (Aghajani, Dezfoulian, Arjroody & Rezaei, 2017; Soltani & Askari, 2014). Traffic accidents vary with the level of development in countries. Traffic accidents form 3% of the Annual Gross Domestic Product in some countries and over 3% in others (Suphanchaimat, Sornsrivichai, Limwattananon & Thammawijaya, 2019).

The increase in the population and the number of vehicles in Turkey has caused traffic to be a problem in the city (Ağın, 2015; Karabulut & Helvacı, 2017). Of these problems, lack of planning, congestion, integration, noise pollution, air pollution, security, lack of infrastructure and not choosing the right type of transportation can be listed (Ağaoğlu & Başdemir, 2019).

Although a decrease in the number of traffic accidents occurring in developed countries has been recorded, such a decrease has not been reported for underdeveloped and developing countries (Mohammed, Ambak, Mosa & Syamsunur, 2019). In Turkey, on the other hand, there are differences in the number of traffic accidents from year to year. Traffic accidents, dead and injured rates and population data for the last 10 years in Turkey are shown (Table 1). While the population of the country increases every year, this increase in traffic accidents is not at the same rate. It is observed that there has been a significant decrease in the number of traffic accidents in 2020. The reason for this is that the restriction of travel in line with the decisions taken due to the pandemic has caused a decrease in the number of vehicles on the road.

Table 1: Number of Traffic Accidents and Population Information in Turkey

Year	Population (Thousand)	Number of Accidents	Number of Material Damage Accidents	Number of Fatal-Injury Accidents	Dead		Injured	
					Number	Ratio to Population (‰)	Number	Ratio to Population (‰)
2011	74.724	1.228.928	1.097.083	131.845	3.835	0,05	238.074	3,19
2012	75.627	1.296.634	1.143.082	153.552	3.750	0,05	268.079	3,54
2013	76.668	1.207.354	1.046.048	161.306	3.685	0,05	274.829	3,58
2014	77.696	1.199.010	1.030.498	168.512	3.524	0,05	285.059	3,67
2015	78.741	1.313.359	1.130.348	183.011	7.530	0,09	304.421	3,86
2016	79.815	1.182.491	997.363	185.128	7.300	0,09	303.812	3,81
2017	80.811	1.202.716	1.020.047	182.669	7.427	0,09	300.383	3,72
2018	82.004	1.229.364	1.042.832	186.532	6.675	0,08	307.071	3,74
2019	83.155	1.168.144	993.248	174.896	5.473	0,07	283.234	3,4
2020	83.614	983.808	833.533	150.275	4.866	0,06	226.266	2,71

There has been an overall increase in the number of registered vehicles, the number of vehicles involved in traffic accidents, and the number of people holding a driver's license in the last 10 years (Table 2). Considering the given numbers and rates, it is seen that traffic accidents constitute an important problem in Turkey. Thus, traffic accidents are an important problem in Turkey and should be considered as one of the most important issues to be solved (Tuncuk, 2004; Çiçek, 2007; Karakaş, Aslan & Karadoğan, 2009; Geymen & Dedeoğlu, 2016; Dereli, 2016; Çağlıyan, Dağlı & Ayhan, 2016; Mohammed et al., 2019).

Table 2: Number of Vehicles Registered to Traffic and Number of Persons with Driver's License in Turkey

Year	Number of Registered Vehicles	Number of Accidents	Ratio of Number of Accidents to Registered Vehicle (‰)	Number of Vehicles Involved in Traffic Accidents	Number of Persons with Driver's License
2010	15.095.603	1.106.201	73,28	156.436	21.548.381
2011	16.089.528	1.228.928	76,38	179.311	22.798.282
2012	17.033.413	1.296.634	76,12	210.609	23.760.346
2013	17.939.447	1.207.354	67,3	251.729	24.778.712
2014	18.828.721	1.199.010	63,68	264.936	25.972.519
2015	19.994.472	1.313.359	65,69	290.072	27.489.150
2016	21.090.424	1.182.491	56,07	295.727	28.223.393
2017	22.218.945	1.202.716	54,13	294.515	28.181.930
2018	22.865.921	1.229.364	53,76	300.704	29.317.724

There are many reasons for traffic accidents to occur. These; driver, passenger, pedestrian, road, vehicle defects and environment (Dezman, et al., 2016; Okafor, Azuike, & Okojie, 2017; Zou & Vu, 2019; Suphanchaimat et al., 2019; Kuşkapan, Alemdar, Kaya & Çodur, 2019; Li et al., 2020). Driver, passenger, pedestrian, road and vehicle defects are among the defects which cause traffic accidents in Turkey between 2013 and 2020 (TÜIK, 2021) (Table 3).

Table 3: Defects Causing Traffic Accidents in Turkey

Year	Driver Defect (%)	Passenger Defect (%)	Pedestrian Defect (%)	Road Defect (%)	Vehicle Defect (%)
2013	88,69	0,42	8,99	1,05	0,85
2014	88,62	0,47	9,38	0,95	0,58
2015	89,30	0,43	8,80	0,91	0,55
2016	89,59	0,41	8,73	0,81	0,47
2017	89,87	0,37	8,48	0,70	0,52
2018	89,46	0,88	8,44	0,60	0,62
2019	88,02	1,26	8,18	0,51	2,03
2020	88,33	1,43	7,00	0,54	2,70

The defects which cause traffic accidents in Turkey in 2020 are given in the table (Table 4). Among the driver's faults which cause traffic accidents, failure to adapt the speed of the vehicle to the conditions required by road, weather and traffic, and not complying with the priority of passing at intersections can be listed as primary defects which cause the accidents. Defective brake is one of the factors which cause accidents in vehicle defects. The most important factor among the passenger defects that cause accidents is not wearing a seat belt and not using a helmet. Loose material on the road surface and potholes are among the road defects which cause accidents. Failure to comply with traffic lights and markers and to act endangering traffic on the vehicle road are important pedestrian defects which cause traffic accidents.

Table 4: Subheadings of Defects Caused by Traffic Accidents in Turkey

#	Driver Defects	%	Vehicle Defects	%	Pedestrian Defects	%
1	Drinking and driving a vehicle	1,19	Defective brake	11,09	Failure to comply with the passing rules in places where there are no crossings and intersections	16,60
2	Failure to adapt the vehicle speed to the conditions required by road, weather and traffic	39,49	Defective rod	2,42	Not obeying traffic lights and signs	29,77
3	Crash from behind	6,90	Scissors, shaft, gearbox, gear failure	0,99	Acting on the vehicle road that endanger the traffic	26,25
4	Driving at excessive speed	1,02	Axle breakage	0,78	Not obeying the traffic rules while crossing the street	2,70
5	Not following the direction change (turn) rules	6,47	Defective steering wheel	1,67	Entering the vehicle road	3,02
6	Passing through prohibited places	0,60	Headlight defect	2,02	Do not drive on the left side of the vehicle road	1,08
7	Not complying with the passing priority at intersections	12,76	Tail lights	1,01	Not taking measures to prevent collisions in cases where visibility is low day and night	6,48
8	Failure to obey a red light or an officer's stop sign	2,38	Turn signal	0,67	Other pedestrian defects	14,10
9	Colliding with properly parked vehicles	1,65	Door defect	1,20		
10	Failure to comply with the general conditions governing maneuvers	8,03	Tire burst	3,20		
11	Infringing of strip	1,52	Other vehicle defects	74,95		
12	Entering places with no vehicles allowed	2,39				
13	Other defects of the driver	15,60				
#	**Road Defects**	%	**Passenger Defects**	%		
1	Scratch	4,68	Not wearing a seat belt, not wearing a helmet	3,34		
2	Line collapse	7,25	Getting on and off vehicles uncontrollably	0,74		
3	Partial collapse	4,91	Other defects of the passenger	95,92		
4	Soft verge	1,23				
5	Loose material on the road surface	21,29				
6	Pothole in the road	14,49				
7	Other road defects	46,15				

The concept of Geographic Information Systems (GIS) emerged in the early 1960s (Aronoff, 1989; Peuquet & Marble, 1990; Goodchild, 2018). In the 1990s, the GIS program was used on desktop computers, making the program more useful and widespread (Marti-Henneberg, 2011; Waters, 2017).

The aim of this study is to examine the factors affecting the distribution of traffic accidents in Bursa between the years 2015-2020. These factors include temporal, spatial, and temporal-spatial. In addition, it is aimed to contribute to the detection, mapping, interpretation of traffic accidents on the highways in the city center and also to the precautions to be taken for these accidents.

STUDY AREA

Bursa is located in the Southern part of the Marmara Region. Sakarya and Bilecik are located in the east of the province, Kütahya in the south, Balıkesir in the west and Yalova and Kocaeli in the north (Figure 2). The total area of the province is 10.886 km². In terms of surface area, it constitutes 1,4% of Turkey's territory. The height of Bursa above sea level is approximately 155 m. 35% of the province is covered by mountains and 17% by plains (BBB, 2021). The prevailing climate in Bursa is temperate. However, it varies from region to region. While a temperate climate is seen in the north with the effect of the Marmara Sea, a colder climate is observed with the effect of Uludağ in the south. The hottest months are between July and September, while the coldest months are between January and March. The annual average temperature of the province is 12.6 ˚C and the average precipitation is 893 mm (Climate-Data, 2021). In 2020, 45.713 people were added to the population residing in Bursa, and the population of the province reached 3.101.833 people. 3,71% of Turkey's population resides in Bursa. The annual population growth of the province is 1.47%. According to population data, Bursa is the fourth largest city in Turkey. The city has 17 districts. Its population is mostly concentrated in two districts. These are Osmangazi (28,42%) and Yıldırım (21,19%) districts (TÜIK, 2021).

There are a number of reasons for choosing the city of Bursa as the study area. One of the reasons was that the cities of Istanbul (Karaman, 2013), Ankara (Kundakçı, 2014) and İzmir (Haybat & Karakaş, 2020; Haybat & Karakaş, 2018) had been studied. Another reason for carrying out the study was that the city of Bursa ranks fourth after the cities mentioned in terms of the number of traffic accidents (TÜİK, 2021). According to the data for 2019, the average number of traffic accidents in Turkey by provinces was 14.422. The number of traffic accidents in Bursa in 2019 was 58.531 (TÜİK, 2021).

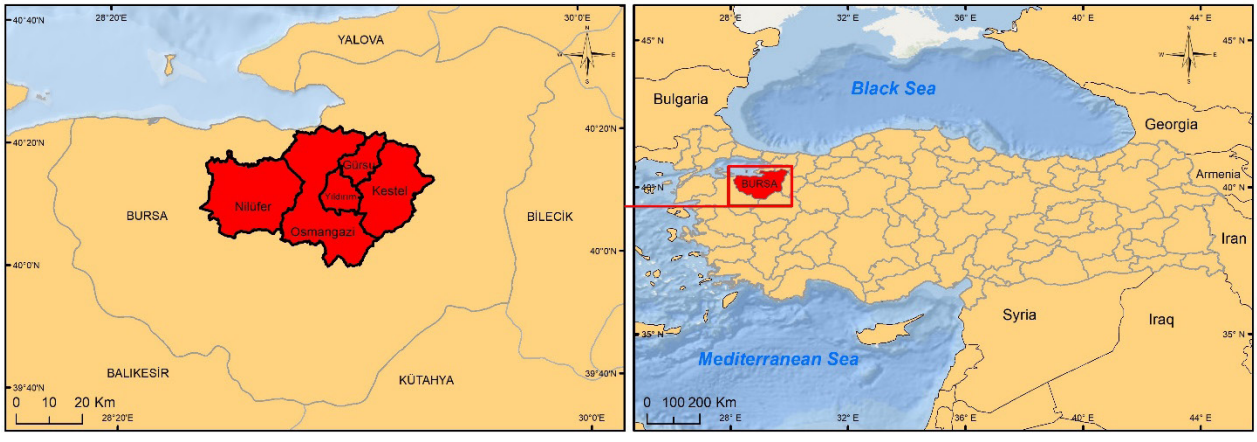


Figure 2: Location Map

DATA AND METHOD

The basic data used in the research are textual traffic accident data consisting of traffic accident reports. In terms of time, traffic accident data covers the years 2015-2020. The time information includes the year, season, month, day and time information of the traffic accidents. The scope of traffic accidents in terms of location consists of five central districts located in the center of Bursa city. The textual data includes the district and location information where the accidents occurred. The most important data is the location information of traffic accidents. Because in the absence of location information, spatial analysis cannot be performed.

In the first stage of data processing, the boundaries of five central districts were created in the ArcGIS environment to determine the boundaries of the study area. In the second process, the data in the excel file containing the traffic accident data were transferred to the GIS environment. In the GIS environment, version 10.8 of ArcGIS program and version 2.5 of ArcGIS Pro program were used. Databases were created in ArcGIS to perform temporal and spatial analysis of the data transferred to the GIS environment. Hour, day, month, season and year information of traffic accidents were entered in order to perform the analysis in terms of temporal. Street, avenue, boulevard, neighborhood and district information were added for spatial analysis. Boulevard and street data were downloaded from OSM's (Open Street Map) web-site (Geofabrik, 2021). In addition, in order to investigate the connection of traffic accidents with land use, land use data was arranged and added to the database according to the study area (Copernicus, 2020).

Five tools were used in ArcGIS to detect traffic accidents. Point density, total case and Anselin Local Moran I tools were used to detect traffic accidents in terms of location. Emerging Hot Spot Analysis and Visualize Space Time Cube's 2D tool were used to detect traffic accidents in terms of temporal and spatial. First of all, the operating logic of the tools should be explained for a better understanding of the subject. Point density tool calculates the density of the points in vector data type and gives it in raster format as output data (Ali Haidery et al., 2020; Cinar & Cermikli, 2019; Costache & Popescu, 2013). Another tool used in the study is the case total tool. The operating logic of the total case tool is that many points are collected in one place and weighted according to the number of collected points (Ali, Khan & Mehmood, 2017; Said, Zahran & Shams, 2017; Corso, Leroy & Alsusdais, 2015; Kuo, Lord & Walden, 2013). Another tool used to detect traffic accidents is Anselin Local Moran I. The purpose of the tool used is to show in which areas traffic accidents are clustered with spatial autocorrelation method by using linear data (Getis & Ord, 1995). The first tool used to detect accidents in terms of time and space is Emerging Hot Spot Analysis. The purpose of this tool is to output data according to the pattern type of the cluster using Mann-Kendall statistics (Kendall & Gibbons, 1990; Mann, 1945). The most recent ArcGIS tool is Visualize Space Time Cube in 2D. The purpose of this tool is to determine the temporal-spatial trend of values at each location using Mann-Kendall statistics.

In the process of examining traffic accidents in terms of time, the connection between traffic accident data and hour, day, month, season and year information was analyzed. When examined in terms of location, traffic accidents were analyzed according to point density, land use, district, neighborhood, highways, total cases and Anselin Local Moran I. Finally, Emerging Hot Spot Analysis and Visualize Space Time Cube in 2D – Trends analysis were carried out in terms of temporal-spatial of traffic accidents. While the data of traffic accidents of 2020 were used in temporal and spatial analyses, the data of traffic accidents of 2020 were not used in temporal-spatial analyses. The reason for this is that while an average of 3.390 traffic accidents occurred between 2015 and 2019, 2.869 traffic accidents occurred in 2020 due to the pandemic, and there was a 15,37% decrease compared to the previous five years. These data are taken from traffic accident reports.

FINDINGS

Analysis of Traffic Accidents in Terms of Temporal

When the traffic accidents which occurred in Bursa between the years 2015-2020 are examined, it is observed that there is no significant difference between the years. However, the curfews across the country due to the covid-19 pandemic in 2020 caused traffic accidents to occur less frequently compared to other years. When the color scales are examined, dark colors show when traffic accidents occur more and light colors show when accidents occur less (Figure 3).

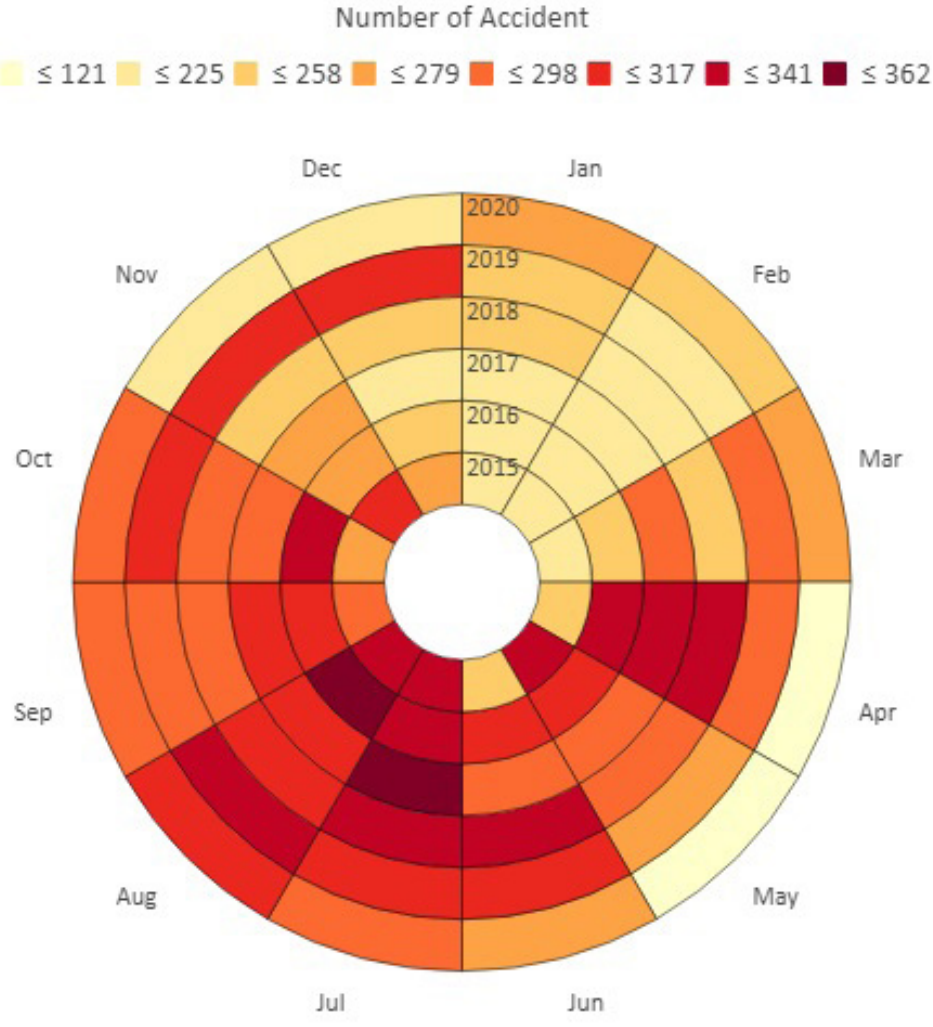


Figure 3: Distribution of Traffic Accidents by Years and Months

Traffic accidents were examined in terms of seasons (Table 5). When the table is examined, traffic accidents occurred mostly in summer months and least in winter months. The increase in traffic accidents in the summer months can be explained by the fact that the weather conditions and the road surface are good, and the vehicle drivers are more careless to obey speed limits. The low number of traffic accidents in winter months can be explained with vehicle drivers driving more carefully due to adverse weather conditions (Zerenoğlu, 2020; Özlü, Haybat & Zerenoğlu, 2020).

Table 5: Distribution of Traffic Accidents According to the Seasons

Season	Year											
	2015	%	2016	%	2017	%	2018	%	2019	%	2020	%
Winter	675	20,78	631	18,23	644	19,04	681	20,21	765	21,94	703	24,50
Spring	786	24,19	896	25,88	911	26,93	886	26,30	864	24,78	494	17,22
Summer	921	28,35	1015	29,32	955	28,23	983	29,18	956	27,42	870	30,32
Autumn	867	26,69	920	26,57	873	25,81	819	24,31	902	25,87	802	27,95
Total	3249	100	3462	100	3383	100	3369	100	3487	100	2869	100

After the seasonal analysis of traffic accidents, the accidents were analyzed by months (Table 6). When traffic accidents are analyzed by months, the least traffic accident occurred in February in all years. The months with the highest number of traffic accidents are the summer months of June, July and August.

Table 6: Numbers and Percentages of Traffic Accidents by Months

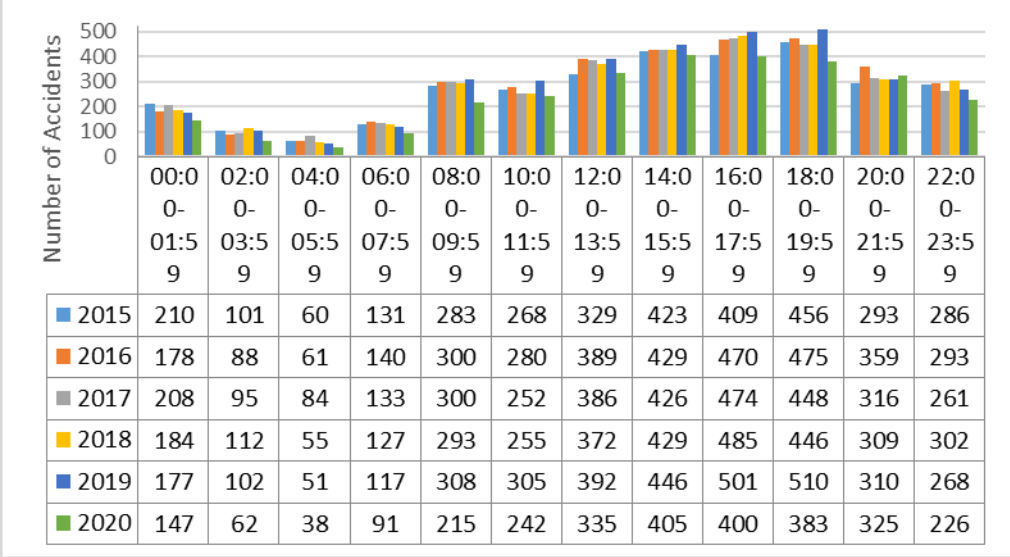
Months	Year											
	2015	%	**2016**	%	**2017**	%	**2018**	%	**2019**	%	**2020**	%
1	219	6,74	203	5,86	207	6,12	242	7,18	256	7,34	262	9,13
2	188	5,79	199	5,75	214	6,33	195	5,79	208	5,97	241	8,40
3	206	6,34	254	7,34	293	8,66	258	7,66	296	8,49	266	9,27
4	250	7,69	331	9,56	325	9,61	335	9,94	291	8,35	121	4,22
5	330	10,16	311	8,98	293	8,66	293	8,70	277	7,94	107	3,73
6	256	7,88	313	9,04	289	8,54	341	10,12	317	9,09	269	9,38
7	337	10,37	340	9,82	355	10,49	331	9,82	310	8,89	298	10,39
8	328	10,10	362	10,46	311	9,19	311	9,23	329	9,44	303	10,56
9	291	8,96	308	8,90	316	9,34	286	8,49	291	8,35	286	9,97
10	274	8,43	333	9,62	287	8,48	287	8,52	309	8,86	291	10,14
11	302	9,30	279	8,06	270	7,98	246	7,30	302	8,66	225	7,84
12	268	8,25	229	6,61	223	6,59	244	7,24	301	8,63	200	6,97
Total	3249	100	3462	100	3383	100	3369	100	3487	100	2869	100

When the distribution of traffic accidents according to the days of the week is examined, it is seen that there is no significant difference between the days, but there is a small increase in the accidents at the weekend. However, it is observed that there is a significant decrease in traffic accidents on Saturdays and Sundays in 2020 compared to previous years. The reason for this is that there was a long period of weekend curfews due to the covid-19 pandemic in 2020 (Table 7).

Table 7: Number and Percentages of Traffic Accidents by Days of the Week

Days of the Week	Year											
	2015	%	2016	%	2017	%	2018	%	2019	%	2020	%
Monday	479	14,74	514	14,85	495	14,63	475	14,10	483	13,85	465	16,21
Tuesday	474	14,59	454	13,11	464	13,72	473	14,04	509	14,60	389	13,56
Wednesday	389	11,97	453	13,08	465	13,75	471	13,98	506	14,51	449	15,65
Thursday	422	12,99	451	13,03	440	13,01	472	14,01	490	14,05	424	14,78
Friday	429	13,20	563	16,26	502	14,84	484	14,37	475	13,62	446	15,55
Saturday	546	16,81	512	14,79	528	15,61	485	14,40	532	15,26	366	12,76
Sunday	510	15,70	515	14,88	489	14,45	509	15,11	492	14,11	330	11,50
Total	3249	100	3462	100	3383	100	3369	100	3487	100	2869	100

Traffic accidents occurred mostly during daylight hours depending on the density of traffic. When the hours of traffic accidents between the years 2015-2020 are examined, it is seen that the accidents mostly occur between 14:00 and 19:59. The least traffic accidents occurred between 00:00 and 07:59 hours, when the traffic density decreased (Figure 4).



	00:00-01:59	02:00-03:59	04:00-05:59	06:00-07:59	08:00-09:59	10:00-11:59	12:00-13:59	14:00-15:59	16:00-17:59	18:00-19:59	20:00-21:59	22:00-23:59
2015	210	101	60	131	283	268	329	423	409	456	293	286
2016	178	88	61	140	300	280	389	429	470	475	359	293
2017	208	95	84	133	300	252	386	426	474	448	316	261
2018	184	112	55	127	293	255	372	429	485	446	309	302
2019	177	102	51	117	308	305	392	446	501	510	310	268
2020	147	62	38	91	215	242	335	405	400	383	325	226

Figure 4: Distribution of Traffic Accidents by Hours

Analysis of Traffic Accidents in Terms of Spatial

The areas where traffic accidents were concentrated between 2015-2020 in Bursa city center were detected (Figure 5). While creating the map, the density level was created in five different classes. In the analysis, the number of traffic accidents per km² is expressed as colors. Accordingly, the areas with the least traffic accidents are shown in blue, and the areas with the most traffic accidents are shown in red. The roads with the highest number of traffic accidents are; Mudanya Street, Ankara Street, Istanbul Street, Sanayi Street and Ulubatlı Hasan Boulevard, which are the main highways.

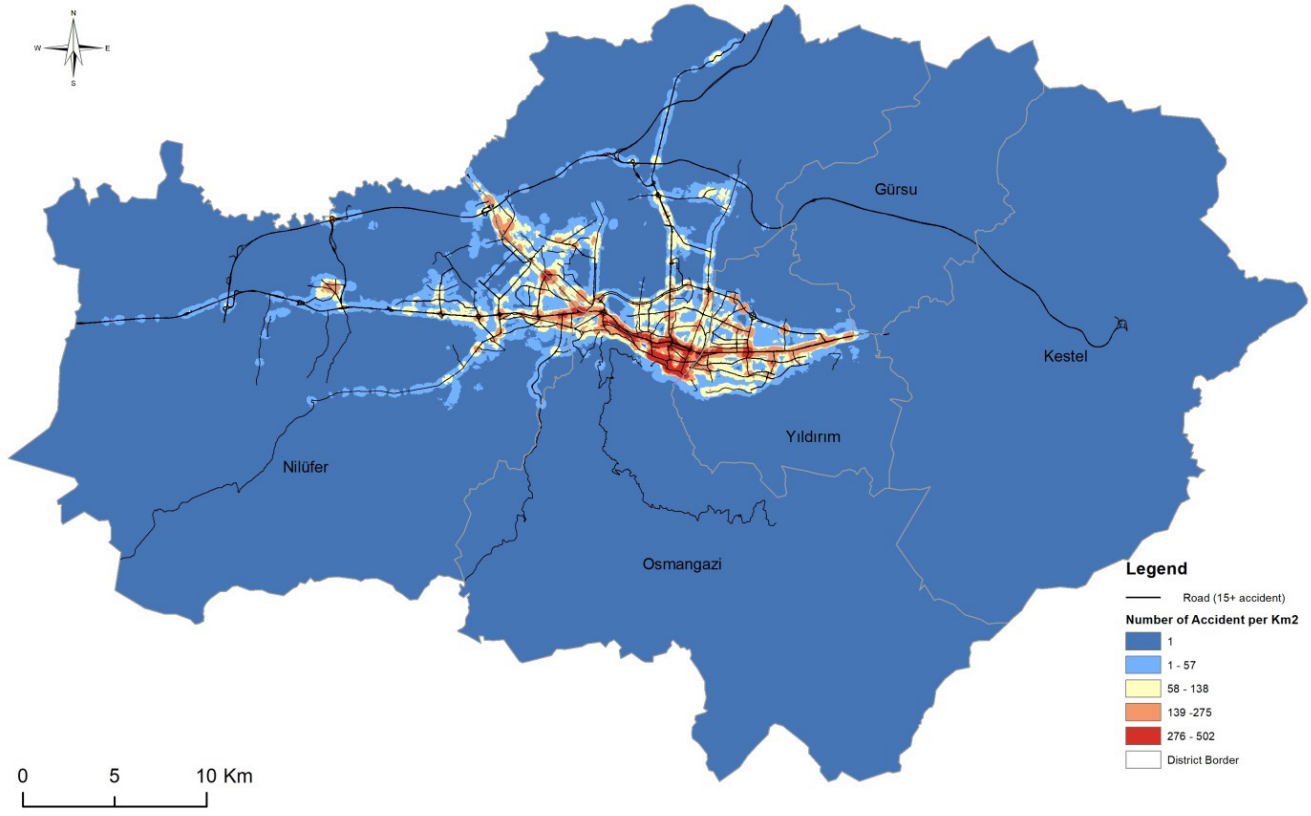


Figure 5: Point Density Map of Traffic Accidents

The purpose of the case collect analysis is to collect more than one point data with the same coordinate information, mainly by grouping the points at one point (Haybat & Karakaş, 2020). In this study, traffic accident points with the same coordinates were mainly grouped by using the case collect tool. A case collect analysis was made by examining traffic accidents for the years 2015-2020 (Figure 6). In the analysis, traffic accident data of six years were used. While conducting the case collect analysis, the roads where the most traffic accidents occurred on the highways were evaluated in five different color groups. The roads with the highest number of traffic accidents are shown in red, orange, yellow, turquoise and blue colors, respectively. Accordingly, the most traffic accidents occurred in Izmir Street, Ankara Street, Istanbul Street and Industry Street, which are shown in red. The least traffic accidents occurred on the highways shown in blue.

By using the case collect tool, the accident black spots of the central districts of Bursa for the years 2015-2020 were determined. Accordingly, a total of 14 accident black spots were identified including Mudanya Street at number 1 black spot; Demirtaş Street at number 2 accident black spot; Yaman Street at number 3 accident black spot; 10. Mercan Sokak at number 4 accident black spot; Mudanya Junction at number 5 accident black spot; 2. Vatan Street at number 6 accident black spot; Millet Street at number 7 accident black spot; Atatürk Street at number 8 accident black spot; Ata Boulevard at number 9 accident black spot; 11 September Boulevard at number 10 accident blask spot; Bilginler Caddesi at number 11 accident black spot; Yunus Emre Boulvevard at number 12 accident black spot; Hürriyet Street at number 13 accident black spot and Dikkaldırım Street at number 14 accident black spot.

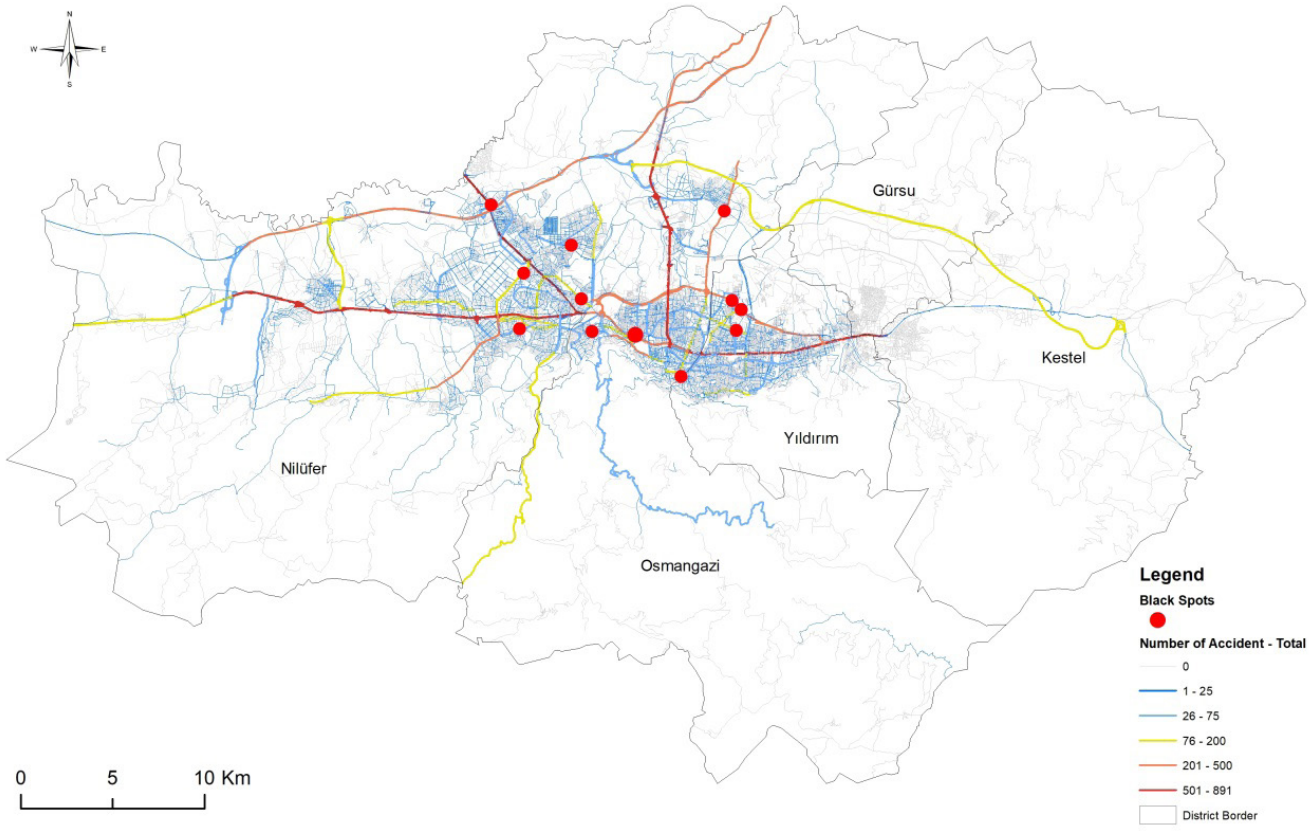


Figure 6: Case Collect Analysis of Traffic Accidents

Traffic accidents were statistically clustered with Anselin Local Moran's I analysis method. Analysis was done using the spatial statistics tool in ArcGIS. While analyzing with this tool, data from traffic accidents on highways were used in the input data. The textual data used are considered weight values in this tool. The analysis of output data; showed that high-high indicated that there was a statistically significant high-value cluster, that is, high-clustering, and that the surrounding highways also had high-clustering. High-low indicated high aggregation, but low aggregation on the highways around or near it. Çanakkale-Bursa Road is shown on the high-high highway. While high clustering occurs on this highway, it is seen that there is high clustering in the surrounding highways. On the high-low highway, there are important highways such as Ankara Street, Izmir Street, Industry Street, Istanbul Street, Mudanya Street and 11 Eylül Boulevard (Figure 7). While high aggregation occurred on these highways, low aggregation occurred on the roads around these highways.

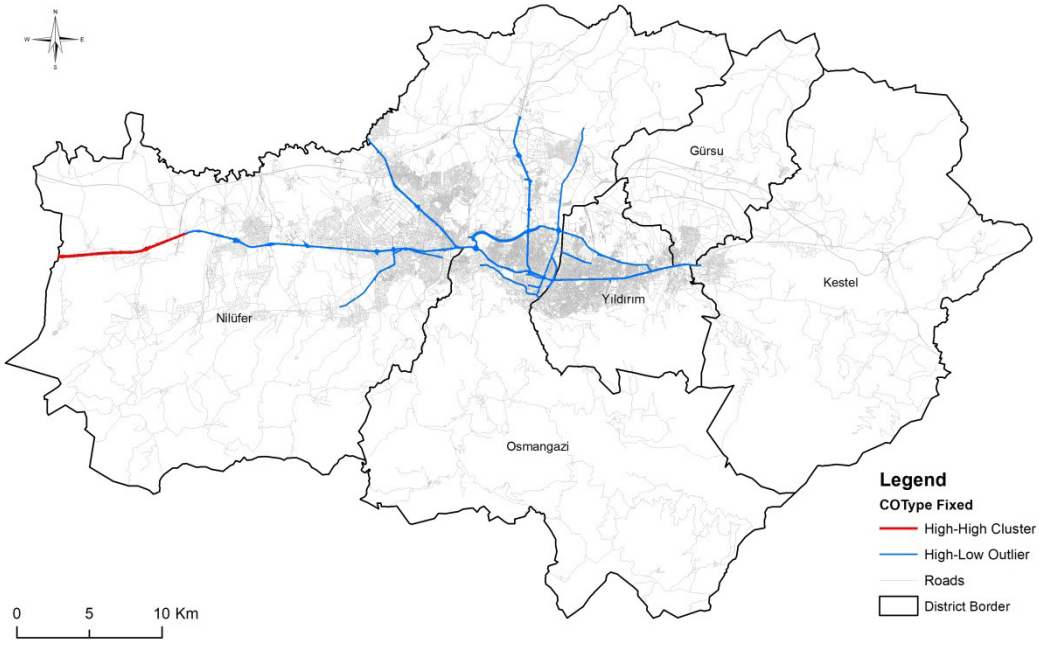


Figure 7: Anselin Local Moran's I Map

The traffic accidents which occurred between 2015-2020 in the central districts of Bursa, Gürsu, Kestel, Nilüfer, Osmangazi and Yıldırım, were examined. When the data of the last 6 years are examined, the most traffic accidents occurred in Osmangazi, which is shown in red, and the least traffic accidents occurred in Kestel, which is shown in blue (Figure 8).

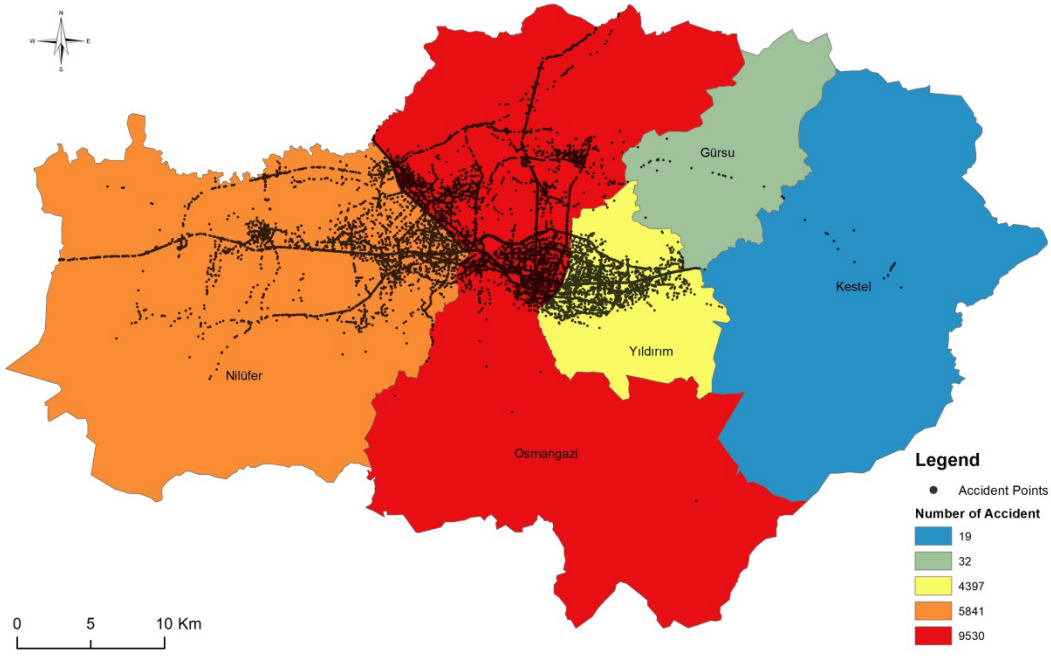


Figure 8: Distribution of Traffic Accidents by Districts

Traffic accidents which occurred in the districts of Osmangazi, Nilüfer, Yıldırım, Gürsu and Kestel, which are the central districts of Bursa between the years 2015-2020, were examined (Figure 9). Neighborhoods with the highest number of traffic accidents are shown in red, and the least number of traffic accidents in blue. Accordingly, the top ten neighborhoods with the highest number of traffic accidents, are Görükle (Nilüfer), Üçevler (Nilüfer), Hamitler (Osmangazi), Kükürtlü (Osmangazi), Küçükbalıklı (Osmangazi), Odunluk (Nilüfer), Yunuseli (Osmangazi), Millet (Yıldırım), Alaşarköy (Osmangazi) and Fethiye (Nilüfer) neighborhoods, respectively.

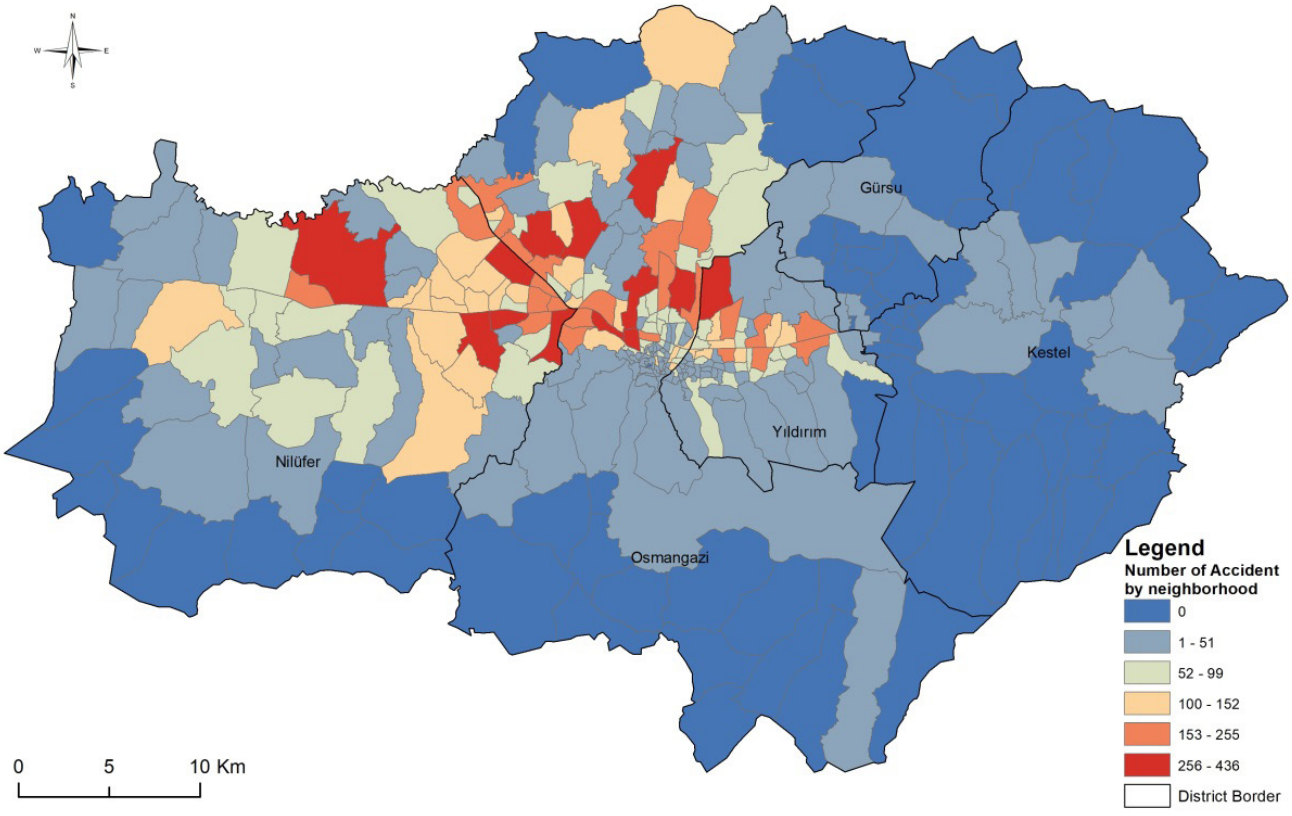


Figure 9: Distribution of Traffic Accidents by Neighborhoods

Analysis of Traffic Accidents in terms of Temporal-Spatial

Traffic accidents in Bursa province were examined in terms of land use (Figure 10). Black dots on the map show traffic accidents. Accordingly, traffic accidents occurred mostly in residential areas, industrial areas and trade centers. The least traffic accidents occurred in sports and entertainment facilities, airports, mining areas, herbaceous vegetation areas and isolated structures.

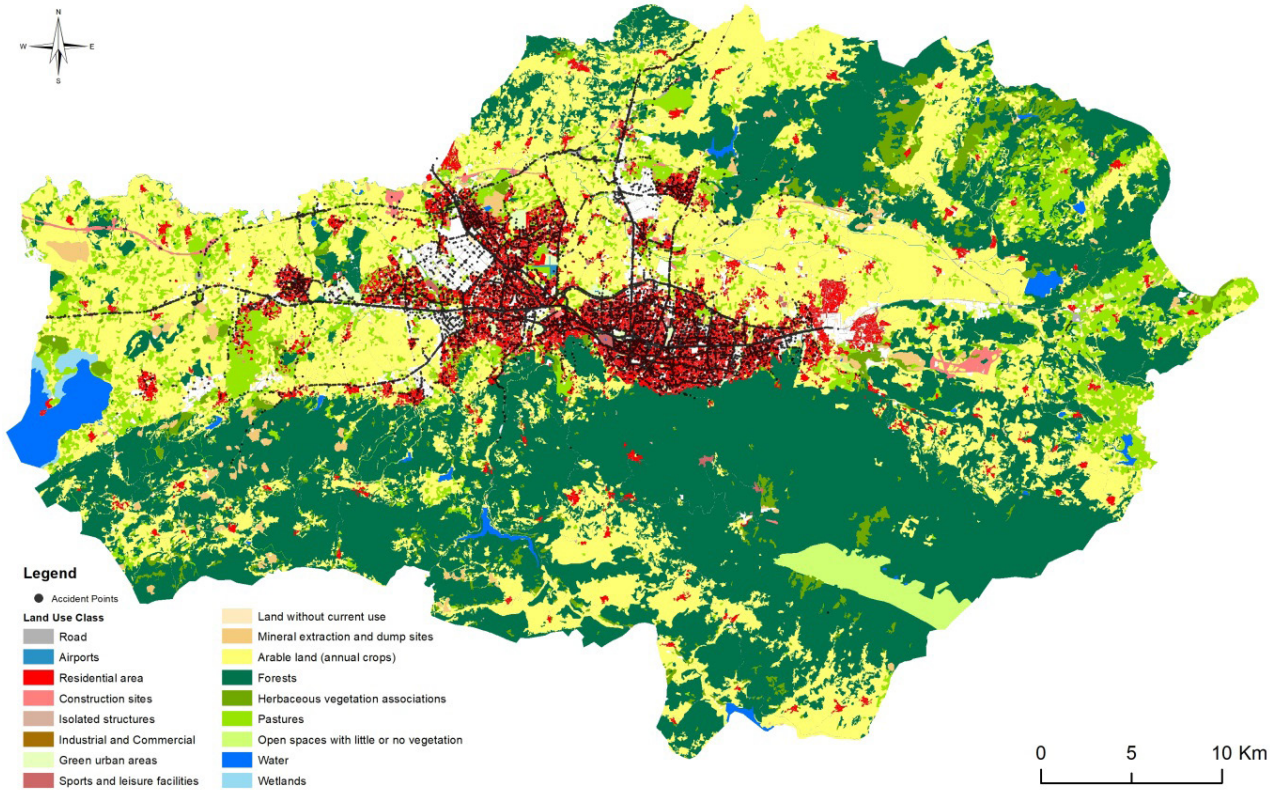


Figure 10: Distribution of Traffic Accidents by Land Use Areas

Traffic accidents in Bursa province are shown as hotspot map (Figure 11). While creating the data, 5-year data covering the years 2015-2019 were used. Because the data set was examined in terms of time and space, it was assumed that the data could give erroneous results due to the curfews in 2020 due to the pandemic. While creating the map, the Emerging Hot Spot Analysis tool under Space Time Pattern Mining Tools was used as the toolkit. The rationale for using this analysis tool is to analyze clusters. These clusters show the densities by adding up the numbers of the dots. Hot spot analysis was evaluated in terms of districts. New Hot Spot in Nilüfer district, Consecutive Hot Spot in Yıldırım district, Intensifying Hot Spot in Yıldırım and Osmangazi districts, Persistent Hot Spot Yıldırım in Osmangazi and Nilüfer districts, Sporadic Hot Spot in Osmangazi, Nilüfer and Yıldırım districts, New Cold Spot in Nilüfer and Osmangazi districts, Consecutive Cold Spot Spot in Osmangazi and Nilüfer districts, Intensifying Cold Spot in Nilüfer, Gürsu and Osmangazi districts, Persistent Cold Spot in Nilüfer and Osmangazi districts, Diminishing Cold Spot in Osmangazi and Nilüfer districts, Sporadic Cold Spot in Osmangazi, Kestel and Nilüfer districts and finally Historical Cold Spot in Nilüfer district are seen.

When the hot spot analysis is evaluated according to land use, it is seen that New Hot Spot and Consecutive Hot Spot areas are in residential areas; Intensifying Hot Spot and Persistent Hot Spot areas are in city cented; Sporadic Hot Spot area is in industrial area; New Cold Spot area is in Çanakkale-Bursa Road and Industry Street; Consecutive Cold Spot Spot areas are located on green zone roads; Intensifying Cold Spot areas are located on forest roads; Persistent Cold Spot areas are located in arable farmland; Diminishing Cold Spot areas are located in sparsely populated residential areas; Sporadic Cold Spot areas are in forest and farmland and Historical Cold Spot areas are located in forest lands.

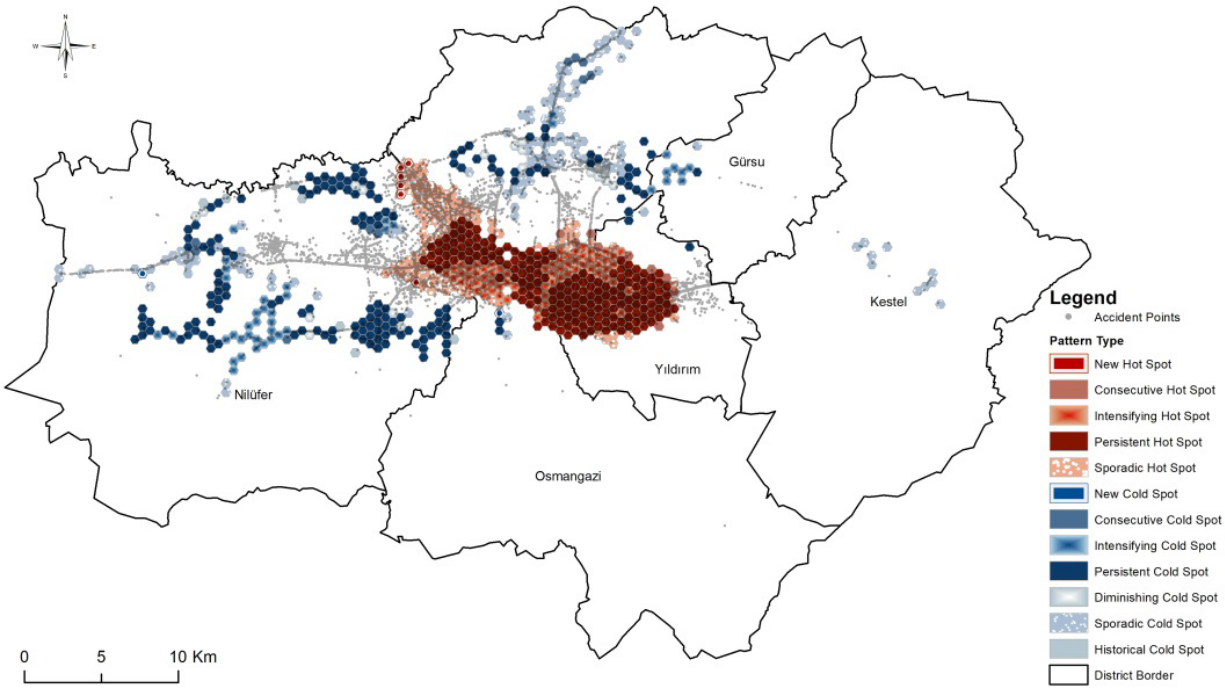


Figure 11: Hotspot Map of Traffic Accidents

Traffic accidents in the province of Bursa are shown as a trend analysis map (Figure 12). While creating the data, 5-year data covering the years 2015-2019 were used. Because the data set was examined in terms of time and space, it was assumed that the data could give erroneous results due to the curfews in 2020 due to the pandemic. Visualize Space Time Cube's 2D tool under Space Time Pattern Mining Tools was used as the toolkit while creating the map. The purpose of this tool is to determine the trends of traffic accidents. It shows that the trend in terms of traffic accident points has increased from the beginning of 2015 to the end of 2019 in the areas shown in purple on the map. In the areas shown in green, it shows that the trend has decreased in terms of traffic accident points from the beginning of 2015 to the end of 2019. As a result of the analysis, there was a trend increase at 7 points. The first point where the trend in traffic accidents increased is Arnavutköy Neighborhood. The reason for the increase in the trend in this neighborhood is the establishment of the Regional Directorate of Highways Public Private Sector Partnership in 2015. The second point is; Demirtaş Cumhuriyet Neighborhood. The reason for the increase in the trend in this neighborhood is the rapid population growth. The third point is; Güneştepe Neighborhood. The reason for the increase in the trend in this neighborhood is the rapid urbanization and population growth. The fourth and fifth points are Hamitler District. The reasons for the increase in the trend in this neighborhood are the fact that Hamitler Sports Facility came into operation and the rapid population growth in the district. The sixth point is; Gorukle Neighborhood. The reason for the increase in the trend in this neighborhood is the fact that Uludag University is located in this neighborhood. The last point where the trend increased is Üçevler Neighborhood. Izmir Street is located in this neighborhood. This street passes through the city center and provides transportation to Uludag University.

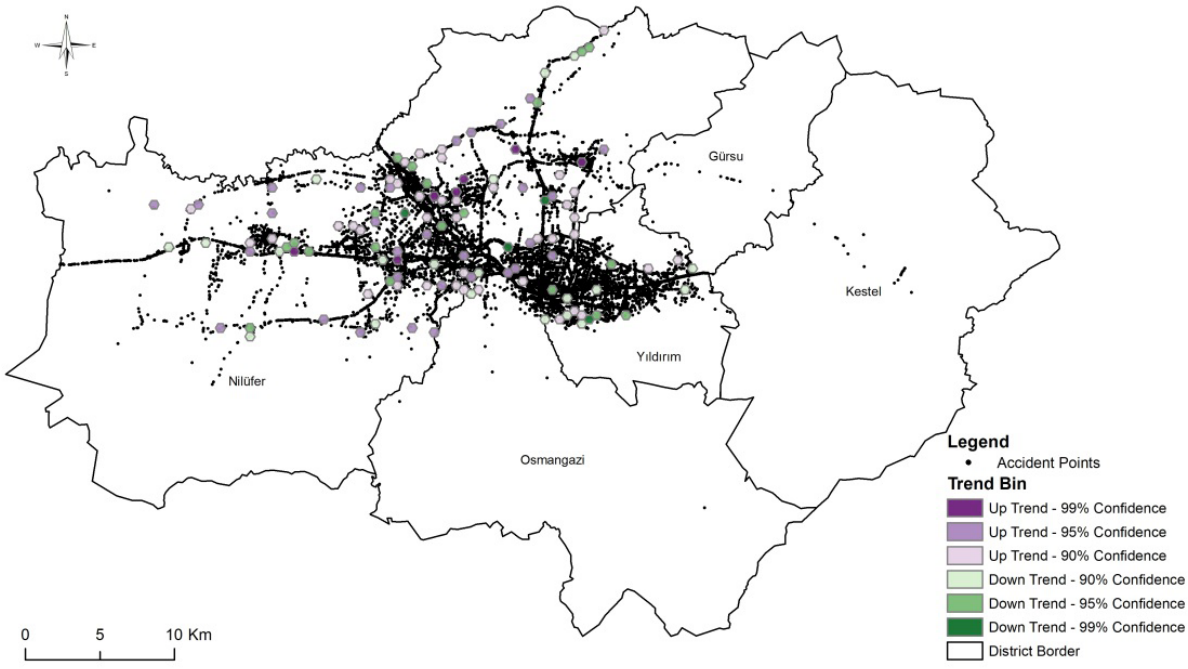


Figure 12: Trend Analysis Map of Traffic Accidents

CONCLUSION

The aim of the research is to examine the distribution of traffic accidents which occurred in the five central districts of Bursa between 2015 and 2020. The distribution of traffic accidents has been examined under three headings in terms of temporal, spatial and temporal-spatial.

The results of this study were classified under three main headings. These are the examination of traffic accidents in terms of temporal, spatial and temporal-spatial. As temporal, year, season, month, day and hour data were used. As a spatial, district, neighborhood, street and highway data were used. As temporal-spatial, traffic accidents data of 2015-2019 were used as time data, excluding 2020 traffic accident data. The reason for not using the accident data for 2020 is that while an average of 3.390 traffic accidents were recorded between 2015 and 2019, 2.869 traffic accidents were recorded with a decrease of 15.17% in 2020, when the global pandemic was experienced. As spatial data, the data of Osmangazi, Yıldırım, Nilüfer, Gürsu and Kestel districts located in Bursa city center were used.

In the first stage of the analysis of traffic accidents in terms of temporal, traffic accidents which occurred between the years 2015-2020 were examined. Between 2015 and 2019, there was no significant difference in traffic accidents on a yearly basis. However, there was a significant decrease in the number of traffic accidents in 2020. The reason for this decline is a significant decrease in traffic accidents as a result of curfews across the country due to the global pandemic in 2020.

Afterwards, the traffic accidents were analyzed in terms of seasons and months. As a result of the examination, seasonally, the season with the least traffic accidents is winter, and the season with the highest number of accidents is summer. As a result of the examination of traffic accidents in terms of months, the least traffic accidents occurred in February and the most traffic accidents occurred in June, July and August, which are summer months.

As a result of the analysis conducted according to the days of the week, there was no significant difference in traffic accidents among weekdays. However, there was a small increase in traffic accidents which occurred on weekends compared to traffic accidents which occurred on weekdays.

Another important issue in the temporal analysis of traffic accidents is the examination of traffic accidents in terms of hours. As a result of the examination, the hours when traffic accidents are most common in all years are between 14.00 and 19.59, which are the hours when traffic density also increases. The least traffic accidents occurred between 00.00 and 07.59 hours when traffic density decreased.

After the evaluation of traffic accidents in terms of temporal, traffic accidents were analyzed in terms of spatial. These places are; districts, neighborhoods, streets and highways. Point Density, Case Total and Anselin Local Moran I analysis tools were used to analyze traffic accidents in terms of spatial.

In the light of the map obtained by using the point density tool of traffic accidents, the intensity level was created in five different classes. In the analysis, the number of accidents per km^2 is expressed with colors. Accordingly, the roads with the highest number of traffic accidents are Mudanya Street, Ankara Street, Istanbul Street, Sanayi Street and Ulubatlı Hasan Boulevard, which are the main highways.

Another tool used in spatial analysis is the case collect analysis tool. In the case collect analysis, traffic accidents with the same coordinate values are grouped. During the analysis, traffic accidents were evaluated as five different color groups. The roads with the highest number of traffic accidents are shown in red and the roads with the least occurrences in blue. Accordingly, the roads with the highest number of traffic accidents are; Izmir Street, Ankara Street, Istanbul Street and Industry Street. In addition, accident black spots were determined by using the case collect analysis tool. A total of 14 accident black spots belonging to five districts located in Bursa city center were determined. These are Mudanya Street, Demirtaş Street, Yaman Street, 10. Mercan Street, Mudanya Junction, 2nd Vatan Street, Millet Street, Atatürk Street, Ata Boulevard, 11 September Boulevard, Bilginler Street, Yunus Emre Boulevard, Hürriyet Street and Dikkaldırım Street, respectively.

Another tool used in the spatial analysis of traffic accidents is the Anselin Local Moran's I tool. With the analysis method made according to this tool, traffic accidents are clustered statistically. Thea analysis of the output data showed that high-high indicated that there was a statistically significant high-value cluster, that is, high-clustering, and that the surrounding highways also had high-clustering. High-low indicated high aggregation, but low aggregation on the highways around or near it. Accordingly, the high-high highway is only seen on the Çanakkale-Bursa Road. On the high-low highway, there are important highways such as Ankara Street, Izmir Street, Industry Street, Istanbul Street, Mudanya Street and 11 September Boulevard.

In the spatial analysis of traffic accidents, analysis was made according to the districts. The maps obtained from the data showed that the highest traffic accident occurred in Osmangazi district, where the population and population density is the highest. The least traffic accidents occurred in Kestel district.

Finally, in the spatial analysis of traffic accidents, analysis was conducted according to the neighborhoods. Accordingly, it was determined that traffic accidents increased in neighborhoods where residential areas and business centers are located. The top ten neighborhoods with the most traffic accidents are Görkle, Üçevler, Hamitler, Kükürtlü, Küçükbalıklı, Odunluk, Yunuseli, Millet, Alaşarköy and Fethiye districts, respectively.

Two tools were used to analyze traffic accidents in terms of temporal-spatial. The first of these is hot spot analysis. The logic of hot spot analysis is to add the numbers of crash spots to show their density. Accordingly, New Hot Spot, Consecutive Hot Spot, Intensifying Hot Spot, Persistent Hot Spot and Sporadic Hot Spot areas and New Cold Spot, Consecutive Cold Spot, Intensifying Cold Spot, Persistent Cold Spot, Diminishing Cold Spot, Sporadic Cold Spot and Historical Cold Spot areas were identified. When the hot spot areas are evaluated according to land use, it was determined that there were hot spots in

the residential area, city center and industrial area. The second and last tool used in traffic accidents examined in terms of temporal-spatial is the trend analysis tool. The purpose of the trend analysis tool is to determine the trend of traffic accidents in the direction of increase or decrease. As a result of the analysis, it was determined that the trend increased at 7 points. These points are located in Arnavutköy District, Demirtaş Cumhuriyet District, Güneştepe District, Hamitler District, Görükle District and Üçevler District.

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REFERENCES

Ağaoğlu, M. N., & Başdemir, H. (2019). Kent içi ulaşim sorunları ve çözüm önerileri. *Gaziosmanpaşa Bilimsel Araştırma Dergisi, 8*(1), 27-36.

Aghajani, M. A., Dezfoulian, R. S., Arjroody, A. R., & Rezaei, M. (2017). Applying GIS to Identify the spatial and temporal patterns of road accidents using spatial statistics (case study: Ilam Province, Iran). *Transportation Research Procedia,* 25, 2126-2138. https://doi.org/10.1016/j.trpro.2017.05.409

Ağın, C. (2015). *Türkiye'de şehirlerdeki toplu ulaşım sistemleri sorunlarının çözümlenmesinde toplumsal davranışların etkilerinin planlama süreci kapsamında incelenmesi. İzmir-Karşıyaka örneği*. (Yüksek lisans tezi, Dokuz Eylül Üniversitesi, Fen Bilimleri Enstitüsü, İzmir). https://tez.yok.gov.tr/UlusalTezMerkezi/ adresinden edinilmiştir.

Ali Haidery, S., Ullah, H., Ullah Klan, N., Fatima, K., Rizvi, S. S., & Kwon, S. J. (2020). Role of Big Data in the development of smart city by analyzing the density of residents in Shanghai. *Electronics, 9*(5), 1-16. https://doi.org/10.3390/electronics9050837

Ali, R., Khan, M. R., & Mehmood, H. (2017). Incidence of violence risk mapping using GIS: A case study of Pakistan. *Journal of Geographic Information System, 9*(6), 623-636. https://doi.org/10.4236/jgis.2017.96039

Aronoff, S. (1989). Geographic Information Systems: A management perspective. *Geocarto International, 4*(4), 58-58. https://doi.org/10.1080/101.060.48909354237

BBB (Bursa Büyükşehir Belediyesi) (2021). 19 Mayıs 2021 tarihinde https://www.bursa.com.tr/tr/sayfa/nufus-konum-iklim-ve-cografya-47/, adresinden edinilmiştir.

Çağlıyan, A., Dağlı, D., & Ayhan, G. (2016). Traffic accident analysis of the city of Elazığ by Geographical Information System. *4th International Geography Symposium.* Antalya, Turkey.

Çiçek, M. (2007). *Trafik bilgi sistemi verileri ile Ankara ili trafik güvenliğinin incelenmesi.* (Yüksek lisans tezi, Gazi Üniversitesi, Fen Bilimleri Enstitüsü, Ankara). https://tez.yok.gov.tr/UlusalTezMerkezi/ adresinden edinilmiştir.

Cınar, H. S., & Cermikli, B. (2019). Point density analysis with cognitive mapping technique: Istanbul-Historical City Center. *Fresenius Environmental Bulletin, 28*(12), 9192-9199.

Climate-Data (Climate-Data.Org) (2021). 19 Mayıs 2021 tarihinde https://tr.climate-data.org/asya/tuerkiye/bursa/bursa-714886/, adresinden edinilmiştir.

Copernicus (2021). 10 Mayıs 2021 tarihinde https://land.copernicus.eu/local/urban-atlas/urban-atlas-2018, adresinden edinilmiştir.

Corso, A. J., Leroy, G., & Alsusdais, A. (2015). Toward predictive crime analysis via Social Media, Big Data, and GIS, and GIS spatial correlation. *In iConference 2015'te sunulmuştur*. Newport Beach. CA, USA.

Costache, R., & Popescu, C. (2013). The touristic accessibility in the Hunedoara county in terms of road network. *Geographia Technica, 8*(12), 1-12.

Dereli, M. A. (2016). *Trafik kaza kara noktalarının belirlenmesi için Coğrafi Bilgi Sistemleri (CBS) destekli mekânsal istatistiksel metotlar ile bir model geliştirilmesi.* (Doktora tezi, Afyon Kocatepe Üniversitesi, Fen Bilimleri Enstitüsü, Afyon). https://tez.yok.gov.tr/UlusalTezMerkezi/ adresinden edinilmiştir.

Dezman, Z., De Andrade, L., Vissoci, J. R., El-Gabri, D., Johnson, A., Hirshon, J. M., & Staton, C. A. (2016). Hotspots and causes of motor vehicle crashes in Baltimore, Maryland: A geospatial analysis of five years of police crash and census data. *Injury, 47*(11), 2450-2458. https://doi.org/10.1016/j.injury.2016.09.002

Geofabrik (2021). 14 Şubat 2021 tarihinde https://download.geofabrik.de/europe/turkey.html, adresinden edinilmiştir.

Getis, A., & Ord, J. (1995). *Local spatial autocorrelation statistics: Distributional issues and an application.* State University Press, 27. https://doi.org/10.1111/j.1538-4632.1995.tb00912.x

Geymen, A. & Dedeoğlu, O. K. (2016). Coğrafi Bilgi Sistemlerinden yararlanılarak trafik kazalarının azaltılması: Kahramanmaraş ili örneği. *Iğdır Üni. Fen Bilimleri Enst. Der., 6*(2), 79-88. https://doi.org/10.21597/jist.201.621.8850

Goodchild, M. F. (2018). Reimagining the history of GIS. *Annals of GIS, 24*(1), 1-8. https://doi.org/10.1080/19475.683.2018.1424737

Haybat, H., & Karakaş, E. (2018). An analysis of traffic accidents with spatial statistical methods in Izmir Province. *Social Science Development Journal,* 3, 599-617. https://doi.org/10.31567/ssd.126

Haybat, H., & Karakaş, E. (2020). Relationship between daily activity areas and traffic accidents in İzmir city. *International Journal of Geography and Geography Education (IGGE),* 42, 429-454. https://doi.org/10.32003/igge.670506

Kababulut, F. Y., & Helvacı, C. (2017). Büyük şehirlerde ulaşım sistemleri ve sorunları: İzmir ili özelindeki sorunlara çözüm önerileri. *Planlama, 27*(3), 215-221. https://doi.org/10.14744/planlama.2017.18894

Karakaş, E., Aslan, H., & Karadoğan, S. (2009). Elazığ şehrindeki trafik kazalarıyla iklim ilişkisinin analizi. *Nature Sciences, e-Journal of New World Sciences Academy, 4*(3), 53-69.

Karaman, E. (2013). *İstanbul'da meydana gelen trafik kazalarının mekansal analizi.* (Yüksek lisans tezi, Fatih Üniversitesi, Sosyal Bilimler Enstitüsü, İstanbul). https://tez.yok.gov.tr/UlusalTezMerkezi/ adresinden edinilmiştir.

Kendall, M. G., & Gibbons, J. D. (1990). *Rank correlation methods.* London: Oxford University Press.

Kundakçı, E. (2014). *Identification of traffic accident hot spots and their characteristics in urban area by using GIS.* (Master's thesis, Middle East Technical University, Geodetic and Geographic Information Technologies, Ankara). Retrieved from https://tez.yok.gov.tr/UlusalTezMerkezi/.

Kuo, P., Lord, D., & Walden, T. D. (2013). Using Geographical Information Systems to organize police patrol routes effectively by grouping hotspots of crash and crime data. *Journal of Transport Geography,* 30, 138-148. https://doi.org/10.1016/j.jtrangeo.2013.04.006

Kuşkapan, E., Alemdar, K. D., Kaya, Ö., & Çodur, M. Y. (2019). Traffic accidents caused by pedestrians in Turkey. *International Journal for Traffic and Transport Engineering, 9*(1), 118-126. https://doi.org/10.7708/ijtte.2019.9(1).09

Levine, J. & Landis, J. D. (1989). Geographic Information Systems for local planning. *Journal of the American Planning Association, 55*(2), 209-220. https://doi.org/10.1080/019.443.68908976022

Levine, N., Kim, K., & Nitz, L. (1995). Spatial analysis of Honolulu motor vehicle crashes: Part I: Spatial patterns. *Accident Analysis and Prevention*, *27*(5), 663-674. https://doi.org/10.1016/0001-4575(95)00017-T

Li, Y., Abdel-Aty, M., Yuan, J., Cheng, Z., & Lu, J. (2020). Analyzing traffic violation behavior at urban intersections: A spatiotemporal Kernel Density estimation approach using automated enforcement system data. *Accident Analysis and Prevention,* 141, 105-509. https://doi.org/10.1016/j.aap.2020.105509

Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica,* 13, 245-59. https://doi.org/10.2307/1907187

Marti-Henneberg, J. (2011). Geographical Information Systems and the study of history. *Journal of Interdisciplinary History, 42*(1), 1-13. https://doi.org/10.1162/JINH_a_00202

Mohammed, A. A., Ambak, K., Mosa, A. M., & Syamsunur, D. (2019). A review of the traffic accidents and related practices worldwide. *The Open Transportation Journal,* 13, 65-83. https://doi.org/10.2174/187.444.7801913010065

Nitin, G., & Adnan, A. H. (2006). Exploring the relationship between development and road traffic injuries: A case study from India. *European Journal of Public Health, 16*(5), 487-491. https://doi.org/10.1093/eurpub/ckl031

Okafor, K., Azuike, E., & Okojie, P. (2017). The causes and prevalence of road traffic accidents amongst commercial long distance drivers in Benin City, Edo State, Nigeria. *Nigerian Journal of Medicine, 26*(3), 220-230.

Özlü, T., Haybat, H., & Zerenoğlu, H. (2020). Temporal and spatial analysis of traffic accidents: The case of Eskişehir City. *International Journal of Geography Education (IGGE),* 43, 136-158. https://doi.org/10.32003/igge.746447

Peuquet, D. J., & Marble, D. F. (1990). *Introductory readings in Geographic Information Systems.* USA: Taylor & Francis.

Said, S. N. B. M., Zahran, E. M. M., & Shams, S. (2017). Forest fire risk assessment using hotspot analysis in GIS. *The Open Civil Engineering Journal, 11*(1), 786-801.

Soltani, A., & Askari, S. (2014). Analysis of Intra-urban traffic accidents using spatiotemporal visualization techniques. *Transport and Telecommunication, 15*(3), 227-232. https://doi.org/10.2478/ttj-2014-0020

Suphanchaimat, R., Sornsrivichai, V., Limwattananon, S., & Thammawijaya, P. (2019). Economic development and road traffic injuries and fatalities in Thailand: An application of Spatial Panel Data Analysis, 2012–2016. *BMC Public Health, 19*(1), 1-15. https://doi.org/10.1186/s12889.019.7809-7

TÜİK (Türkiye İstatistik Kurumu), (2021). 23 Haziran 2021 tarihinde http://www.tuik.gov.tr, adresinden edinilmiştir.

Tümertekin, E. (1987). *Ulaşım coğrafyası.* İstanbul: İstanbul Üniversitesi Yayınları.

Tuncuk, M. (2004). *Coğrafi Bilgi Sistemi yardımıyla trafik analizi: Isparta örneği.* (Yüksek lisans tezi, Süleyman Demirel Üniversitesi, Fen Bilimleri Enstitüsü, Isparta). https://tez.yok.gov.tr/UlusalTezMerkezi/ adresinden edinilmiştir.

UNECE (The United Nations Economic Commission for Europe), (2020). 20 Mart 2020 tarihinde *https://www.unece.org/unrsf/about-the-fund.html,* adresinden edinilmiştir.

Waters, N. (2017). *The international encyclopedia of geography.* New York: John Wiley & Sons.

WHO (World Health Organization), (2018). 06 Mayıs 2020 tarihinde https://www.who.int/gho/publications/world_health_statistics/2018/en/, adresinden edinilmiştir.

Yardımcıoğlu, F. (2013). *Ulaşım hizmetleri (kamu hizmetleri perspektifi).* Bursa: Dora Yayıncılık.

Zerenoğlu, H. (2020). *Trafik kazalarının mekânsal analizi: Eskişehir örneği,* (Yüksek lisans tezi, Ondokuz Mayıs Üniversitesi, Lisansüstü Eğitim Enstitüsü, Samsun). https://tez.yok.gov.tr/UlusalTezMerkezi/ adresinden edinilmiştir.

Zou, X., & Vu, H. L. (2019). Mapping the knowledge domain of road safety studies: A scientometric analysis. *Accident Analysis and Prevention,* 132, 105-243. https://doi.org/10.1016/j.aap.2019.07.019