Research Square

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Spatio-temporal Analysis of Cardiovascular Emergency Medical Requests: To Inform Policy and Practice

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Abstract

Background:

Response time to cardiovascular emergency medical requests is an important indicator in reducing cardiovascular disease (CVD) related mortality. This study aims to develop an index of response time and investigate potential clusters in the pattern of CVD-related calls over time and space.

Methods:

This cross-sectional study was conducted in Mashhad, north-eastern Iran, between August 2017 and December 2019. An emergency medical service (EMS) response time matrix to CVD-related calls was computed using spatial and classical statistical analyses. The Anselin Local Moran's *I* was performed to identify potential clusters in the patterns of CVD-related calls, response time, call-to-hospital arrival time, and scene-to-hospital arrival time at small area level (neighborhood level) in Mashhad, Iran.

Results:

There were 84,239 CVD-related emergency request calls, of which 60.21 percent were transported to clinical centers by EMS, and 2.62 percent (a total of 2203 persons) died before EMS arrival. The number of CVD-related emergency calls increased by almost 15% in 2018 and 20% in 2019. The peak in the number of calls occurred between 9 p.m. and 1 a.m., and the lowest number of calls were recorded between 3 a.m. and 9 a.m. Saturday was the busiest day of week in terms of call volume. There were statistically significant clusters in the pattern of CVD-related calls in the south-eastern region of Mashhad. Further, we found a large spatial variation in scene-to-hospital arrival time and call-to-hospital arrival time in the area under study.

Conclusion:

The use of geographical information systems and spatial analyses in modelling and quantifying EMS response time provides a new vein of knowledge for decision makers in emergency services management. This also enables policy makers to design tailored interventions to improve response time and reduce CVD-related mortality.

Background:

Non-communicable diseases accounted for about 73% of the total number of deaths worldwide in 2016. Of these, cardiovascular disease (CVD) was the primary cause of premature mortality, accounting for an estimated total of 9.48 million deaths worldwide, which signifies a 19% increase between 2006 and 2016 (1, 2). In Iran, there were 90,000 reported CVD-related mortalities in 2016, amounting to 25% of the total number of deaths (3). This is despite the fact that premature CVD mortalities can often be prevented with timely delivery of emergency medical services (3). Therefore, decreasing the response time in CVD-related emergency requests is of great importance.

CVDs include ischemic heart disease or coronary artery disease (CAD) such as angina and myocardial infarction (MI) (commonly known as a heart attack), cerebrovascular disease (e.g. stroke), diseases of the aorta and arteries, including hypertension and peripheral vascular disease, congenital heart disease, rheumatic heart disease, cardiomyopathies and cardiac arrhythmias (4). Among these, MI is the most important in terms of mortality rate. MI occurs as a result of a complete blockage of one of the main coronary arteries (5). In the case of MI, the standard clinical procedure is to restore blood flow in the blocked artery, so as to avoid myocardial necrosis and restore heart function, thus reducing the risk of mortality. Damage to the heart muscle as a result of MI increases with time after blockage of the artery. Interventions that are able to facilitate the diagnosis and treatment of MI can potentially lead to reduced CVD-related mortalities and associated complications, and improve patients' quality of life (6–8).

In Iran, the emergency medical services (EMS) are responsible for transferring patients to clinical centers. A patient experiencing a cardiovascular event calls 115 and an ambulance is sent to the patient's residence (scene) to assess their health status and, if deemed necessary, transfer them to the nearest health care center. Response time is the time between a patient's call and ambulance arrival at the scene. A quick response time is critical to enable effective delivery of clinical intervention in cardiovascular emergencies. To the best of our knowledge, there is no research conducted to analyze EMS response time for CVD incidents in Iran. Developing an index of EMS response time will provide the essential knowledge to enable policymakers, healthcare providers and clinicians to improve response time, and ultimately reduce MI mortality rate. Further, this response time index needs to be adjusted to account for patients' geographical locations and time of day.

Geographical information systems (GIS) is an emerging area of research, which is increasingly being used as a decision support tool for policy makers to develop tailored interventions in health care (9–12). GIS is a powerful tool to collect, manage, analyze and represent geo-referenced health data, and identify gaps in health care systems. GIS enables researchers to integrate spatial (location of health care services as geographical entities: patient locations and ambulances dispatch centers) and non-spatial data (descriptive information on geographical entities; opening hours, waiting list, etc.) into one framework to provide better informed decision making (13). There are several research reports on GIS application to the modelling of spatial accessibility and response time to EMS across the world. The main focus points of these studies were: measuring spatio-temporal accessibility (14); spatial variations of EMS and travel distance (15); spatial diversity of response time for EMS (16); the geographic-time distribution of all ambulance calls and hourly and weekly EMS call volumes (17); and conditional autoregressive spatial models to identify drivers of cardiac arrest (18).

To our knowledge, there is no study in Iran which examines the space-time pattern of CVD-related emergency medical requests. The purpose of the present study is to perform a spatial-time analysis of cardiovascular emergency medical requests using GIS in Mashhad, Iran. Our specific objectives are to: 1) geocode EMS requests and develop a spatial database to link with other attributes of EMS; 2) develop the first index of response time for CVD-related EMS calls in Iran; and 3) investigate potential clusters in the pattern of CVD-related calls over time and space.

Methods:

Study Area and data sources:

This study was conducted in Mashhad, north-eastern Iran, with a population of 3,785,567 (Fig. 1). Mashhad is the most popular tourist destination and the second most populous city in Iran (19). Mashhad has 149 neighborhoods which are divided into census blocks, the smallest unit of spatial divisions in cities of Iran. In this study, we used neighborhood catchment as the geographical scale for performing the spatial analyses. Mashhad neighborhoods have an average population of 18,523 and a mean area of 1.92 square kilometers.

Data Sources:

Two different data sources were used. First, data from CVD-related emergency calls were obtained from Mashhad Emergency Medical Center. The data did not contain cerebrovascular disease (e.g. stroke) incidents. Second, the spatial division of Mashhad and population data were obtained through the city municipality.

Descriptive analysis:

All descriptive analyses (cross tabulations and frequency indices) were performed using Excel version 2016. Descriptive maps were generated using natural break classification with five classes. Natural break classification is a data grouping method designed to determine the best arrangement of values into different classes. This is conducted by seeking to minimize each class's average deviation from the class mean, while maximizing each class's deviation from the means of the other groups. In other words, the method seeks to reduce the variance within classes and maximize the variance between classes (20). ArcGIS 10.5 was used for creating the descriptive maps and spatial-time analyses.

Cluster and outlier analysis:

The incidence rate of CVD-related emergency calls was calculated using the total population and number of calls in each neighborhood across the study area. The Anselin Local Moran's *I* statistic was performed to quantify spatial autocorrelation of call frequency at the neighborhood level. This test calculates a z-score and p-value to determine whether the apparent similarity (a spatial clustering of either high or low values) or dissimilarity (a spatial outlier) is more pronounced than one would expect in a random distribution. The null hypothesis states that CVD-related emergency calls are randomly distributed across the study area. Areas with High-High and Low-Low clusters indicate that the target neighborhood is encompassed by neighborhoods with similar rates of CVD-related emergency calls, while High-Low and Low-High regions show that the target area is encompassed by regions with dissimilar rates of CVD-

related emergency calls (9). In other words, the High-High and Low-Low areas indicate clusters of CVD-related emergency calls occurrence, but the High-Low and Low-High areas indicate outliers of CVD-related emergency call frequencies.

Statistical Significance:

Anselin local Moran's *I* calculates a z-score and p-value for each feature in the dataset. P-value and z-score are closely associated. The p-value is the probability that the observed spatial pattern was created by some random process. A high positive z-score for a feature indicates that the surrounding features (neighboring CVD-related call values) have similar values (either high values or low values). However, a low negative z-score for a feature indicates a statistically significant spatial data outlier. Table 1 shows the range of z-scores and p-values used for testing the statistical significance. We used a 95% confidence level in this study, and all clusters and outliers found in this study were significant at this confidence level.

Table 1
Z-score and p-value ranges of Anselin local Moran's *I*

Z-score (standard deviations)	P-value (probability)	Confidence level
< -1.65 or > + 1.65	< 0.10	90%
< -1.96 or > + 1.96	< 0.05	95%
< -2.58 or > + 2.58	< 0.01	99%

Results:

Figure 1 shows the geographical distribution of CVD-related emergency calls in Mashhad from August 2017 until the end of 2019. There were 84,239 calls, the characteristics of which have been mapped in Table 2. It shows that only 60.21 percent of individuals making calls were transferred to a hospital, a figure which remained the same for each year of the study. Furthermore, on average, 2.62 percent of people (2203 persons) died before an ambulance reached their location. The mean age of men was lower than that of women. The response time decreased from 11.35 minutes in 2017 to 11.07 minutes in 2019, but the time from leaving the patient's location to arriving at hospital increased from 10.21 minutes in 2017 to 12.13 minutes in 2019.

Table 2
Characteristics of CVD-related emergency calls in the city of Mashhad from August 2017 until the end of 2019

Characteristics	All patients (n = 84,239)	2017 (23 Aug-30 Dec)	2018 (1 Jan- 30 Dec)	2019 (1 Jan- 30 Dec)
Mean age ± SD (n = 84,226)	52.97 ± 30.40	53.54 ± 18.41	52.62 ± 18.78	52.68 ± 18.79
Men mean age ± SD	52.13 ± 39.07	52.47 ± 18.73	51.72 ± 19.13	51.76 ± 18.99
Women mean age ± SD	53.58 ± 18.47	54.46 ± 18.08	53.38 ± 18.45	53.48 ± 18.57
Male (n ;%)	38812 (46.09%)	5334 (46.28%)	15570 (45.32%)	17908 (46.72%)
Women (n ;%)	45397 (53.91%)	6192 (53.72%)	18786 (54.68%)	20419 (53.28)
(Call receipt – arrival mean) ± SD (n = 80,747)	11.35 ± 6.5	12.33 ± 5.48	11.36 ± 6.46	11.07 ± 6.77
Scene interval min ± SD (n = 51,978)	13.02 ± 7.77	14.83 ± 11.21	12.71 ± 6.56	12.81 ± 7.53
(Leave location – hospital) min ± SD (n = 42,649)	11.69 ± 8.63	10.21 ± 11.47	11.54 ± 8.19	12.13 ± 8.17
Number of call (monthly Average)	84,239 (2977)	11,533 (2160)	34,361 (2863)	38,328 (3194)
Action Result (n = 84,239; %)				
Transport to medical center	50720 (60.21%)	6814 (59.08%)	21201 (61.70%)	22694 (59.21%)
Lack of patient cooperation	29233 (34.70%)	4171 (36.17%)	11719 (34.11%)	13338 (34.80%)
The patient died before the ambulance arrived	2203 (2.62%)	320 (2.77%)	797 (2.32%)	1086 (2.83%)
Transmission during cardiac resuscitation	1198 (1.42%)	69 (0.6%)	420 (1.22%)	709 (1.85%)
Others	885 (1.05%)	159 (1.38%)	224 (0.01%)	501 (0.01%)

(Call receipt – arrival) or Response time: time interval between the time when the call is made and the time when the emergency ambulance reaches the patient (21); Scene interval: the time duration of the

presence of emergency technician at the scene (21); (Leave location – hospital): The time period between ambulances leaves patient location to the hospital (21).

Figure 2 shows the monthly temporal trend of CVD-related emergency calls in the study area between 2017 and 2019. It also indicates that the number of CVD-related emergency calls increased by almost 15% in 2018 and 20% in 2019. Furthermore, the figure reveals that most CVD-related emergency calls occurred in November and December.

Figure 3 shows the seasonal distribution of CVD-related calls in Mashhad in 2017–2019. The highest response time was observed in the middle of summer and autumn. The figure reveals that the average response time and the average scene interval time decreased, while the average time from leaving the patient's location to arriving at hospital increased.

Figure 4 shows the distribution of CVD-related emergency calls according to the time of day. The highest number of calls occurred between 9 p.m. and 1 a.m., and the lowest number of calls occurred between 3 a.m. and 9 a.m. This trend was maintained throughout the entire period of study (2017–2019). Figure 5 shows the distribution of CVD-related emergency calls according to week days. Saturdays had the highest call volumes across all three years. It is the first working day of the week in Iran.

Figure 6 shows the geographical distribution of CVD-related emergency calls at the neighborhood level in the city of Mashhad, Iran. This graph highlights that there was a high-high cluster of the incidence of the CVD-related calls in the south-eastern area of Mashhad.

Figure 7 shows the geographical distribution of call-to-hospital time, response time, and scene-to-hospital time of emergency CVD-related medical calls in Mashhad from August 2017 until the end of 2019.

Figure 8 shows that call-to-hospital-arrival time and scene-to-hospital-arrival time are the same in terms of geographical distribution at neighborhood level. However, spatial distribution of response time is different from both call-to-hospital-arrival-time and scene-to-hospital-arrival time.

Figure 9 shows the areas where CVD-related mortality is significantly higher and high-high clusters of mortality were observed in center-south part of the study area.

Discussion:

The main aim of the present study was to develop an index of EMS response time for CVD-related calls between 2017 and 2019. Our main findings suggest that there is a significant variation in EMS response time over space and time, with significant clusters of low/or high response time and CVD-related mortality in Mashhad.

Previous studies highlight that clinical events and calls to clinical emergency services are not random, and follow a regular pattern. This pattern depends on specific time of the day, levels of car traffic, places of residence and commuting throughout the city, and other epidemiologic and demographic factors (17).

Sudden myocardial infarctions, for example, follow a regular pattern of occurrence (22–25), with most events occurring between morning and noon (26, 27). Moreover, some studies report seasonal or weekly patterns of occurrence of myocardial events, with a reported increase on Mondays (28–31). Our study findings highlighted that the number of emergency requests follows a pattern of increased incidence between morning and noon, in line with the findings of previous studies. Moreover, we also observed an increasing pattern of emergency calls between 6 pm and midnight. This pattern was observed consistently across all days of the week from 2017 to 2019 (Fig. 4). Given the fact that a previous study (32) identified sudden wake-up and heavy workload as the main risk factors for myocardial infarction, these two factors could explain the higher rate of incidence in the morning (sudden wake-up) and evening (heavy workload). Moreover, while in some studies the weekly pattern of peak incidence rate was identified as occurring on Mondays, in our study this was found to be Saturdays (Fig. 5). This is likely to be due to the difference between the working week in Iran and that of the rest of the world. In Iran, Saturday is the first day of the week, and Friday is considered to be the weekend. The lowest rate of calls was recorded on Thursdays in the first year of study, and on Fridays in the second and third year of the study. Although Fig. 2 shows that the volume of delivered emergency services has increased by 15% in 2018 and 20% in 2019, a general look at the delivered services reveals that the ratio of cardiovascular-related emergency services to the total number of emergency services is 17.4, 17.5, and 17.3 for the past three calendar years, respectively. We could therefore interpret this to mean that not only CVD call requests, but all emergency calls, have increased.

Figure 6 shows the spatial distribution of EMS calls, demonstrating that the south-eastern areas of Mashhad have the highest number of emergency service requests. This is an area in proximity to the Holy Shrine, which is a central destination for tourists and a pilgrimage location. It is an area with a high concentration of hotels, residential complexes and shopping malls. As such, there is a high population density and heavy traffic congestion in this area as compared to the rest of Mashhad.

The most important temporal criterion in assessing the performance of the pre-hospital emergency services is response time. The standard response time is 8 minutes, which is directly related to higher survival rate and reduced mortality (33). The average response time for the three consecutive years was calculated as 11.35 ± 6.5 minutes, showing a pattern of decreasing response times: 12.33 ± 5.48 in 2017, 11.36 ± 6.46 in 2018 and 11.07 ± 6.77 in 2019. Another important criterion in assessing the performance of pre-hospital emergency services is scene interval, which represents the duration of time emergency technicians are present at the scene. The global gold standard for this criterion is 10 minutes (34). Patients should be managed in such a way so as to minimize delays in their transfer to clinical centers. In Iran, scene interval is typically less than twenty minutes (21). The average scene interval was calculated as 13.02 ± 7.77 minutes for the past consecutive three years, showing a decreasing pattern. Although both these criteria lag far behind global standards, this difference is not uniformly distributed across different areas of the city.

Cluster maps in Fig. 8 show significant differences in the performance of emergency departments across different areas of the city in relation to temporal criteria. A thorough analysis reveals that in the central

areas of the city, where response time is high, there is no problem in terms of call to hospital time and scene to hospital time. The high response time may relate to a high volume of calls in this area due to its population density, leading to an increased response time in the central area of Mashhad. On the contrary, in the southern and rural areas of the city, which have a good response time, a weak call to hospital time and scene to hospital time is observed. This problem is likely due to the fact that the location of emergency dispatch centers is not properly linked with their respective hospitals. This should be taken into account to improve health standards and survival rate of patients.

The cluster map of Fig. 9 shows the mortality rate of patients with myocardial infarction who died before ambulance arrival. As can be observed, the south eastern area is associated with a significantly higher risk of mortality when compared to other areas. An analysis of the mean age for these subjects indicates that they have a higher mean age (71.91 ± 20.07). This is observed across all three years.

Previous studies report that a higher response time is directly associated with a higher rate of mortality (33). Although the response time is shorter in this group of patients (9.62-minute vs 11.35 for the entire population), the mortality rate is higher when compared to that of the total population. This needs to be investigated further to identify drivers (risk factors) of CVD related mortality other than response time. Some of these risk factors include patients' age, delays in requesting emergency services, previous history of disease, lack of knowledge about heart disease, and loneliness and life style, which are mentioned in previous studies (35, 36). Given that the mean age of this group of patients is significantly higher than the rest of the population, it could be speculated that because of the higher age, other factors such as loneliness, low health literacy, previous disease history (more advanced disease, more comorbidities as a result of older age) could be the most significant driver of increased mortality despite quick response time in older people

Limitations:

No data was available about the time interval between the onset of chest cardiac symptoms and the decision by the patient to request emergency services, which is an important determining factor for patient survival.

Conclusion:

The use of geographical information systems (GISs) and spatial analyses in modelling and quantifying EMS response time by integrating spatial and temporal data into one framework provides a new vein of knowledge for decision makers in emergency services management. This also enables policy makers to design tailored interventions to improve response time and reduce CVD-related mortality.

Abbreviations

cardiovascular disease (CVD); coronary artery disease (CAD); myocardial infarction (MI); emergency medical services (EMS); Geographical information systems (GIS).

Declarations

Ethics approval and consent to participate

The study was approved by the ethics committee of the Research Department of Mashhad University of Medical Sciences protocol number: IR.MUMS.MEDICAL.REC.1399.146. Inform consent was not obtained due to the nature of the study and the ethical committee approved that.

Consent for publication

Not applicable because we used the data of EMS centre which did not include any identification items.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author (B.K) on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

B.K, A.A and M.M and N.B drafted the manuscript. N.B and M.F critically reviewed and edited the first draft. S.H contributed to spatial analyses. F.HA geocoded the data. S.E reviewed the manuscript and contributed to study design. B.K designed the study, interpret the results and supervised the research. R.V, F.K, A.G and T.K contributed to data cleaning and preparing the data for analyses. All authors read and approved the final manuscript for submission.

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Figures

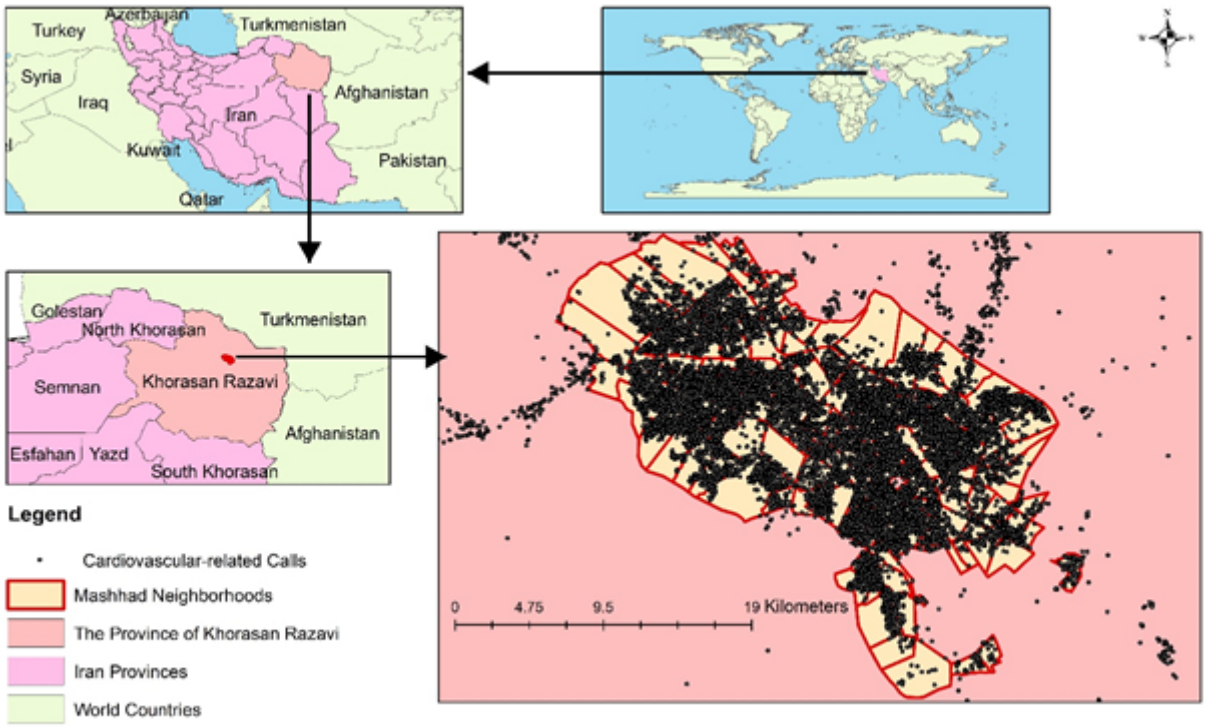


Figure 1

Geographical distribution of cardiovascular-related emergency calls in Mashhad, Iran. The figure created by authors.

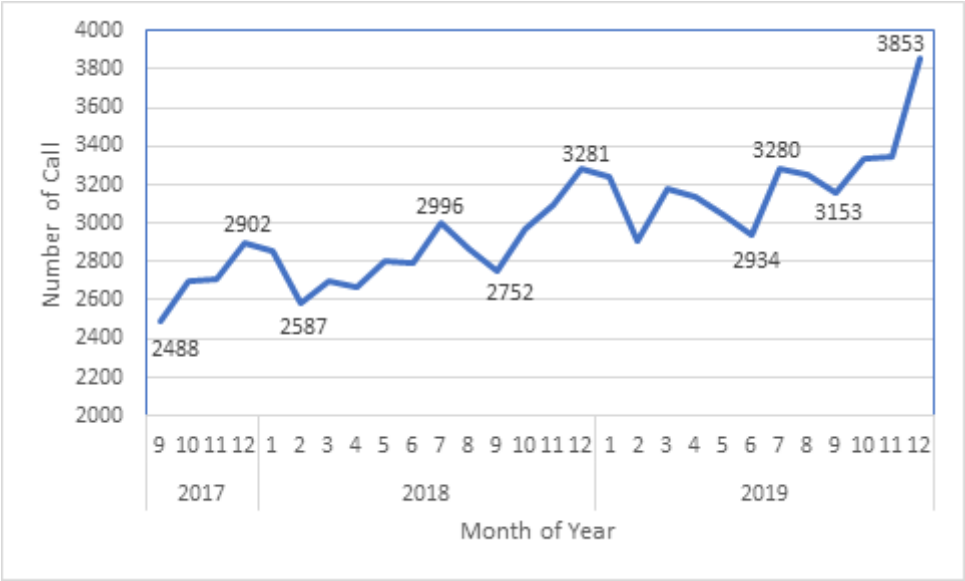


Figure 2

Monthly frequency of CVD-related emergency calls in the city of Mashhad, Iran during 2017-2019

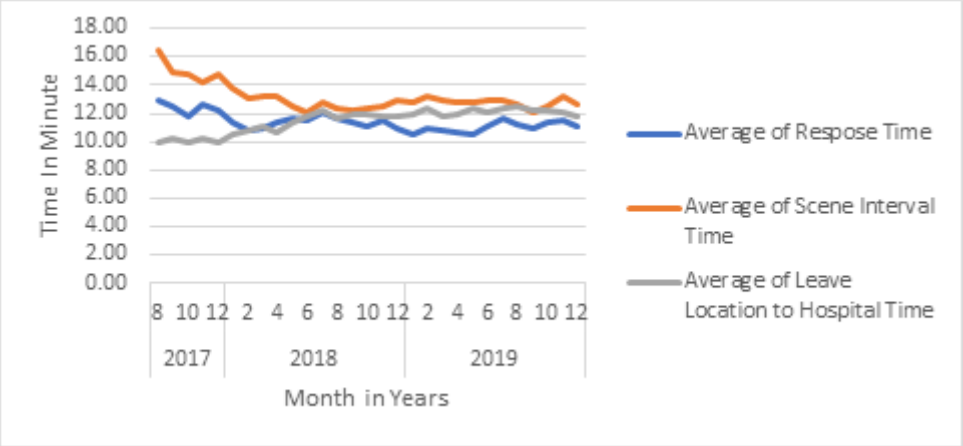


Figure 3

Seasonal distribution of cardiovascular-related calls in the city of Mashhad, Iran in 2017-2019

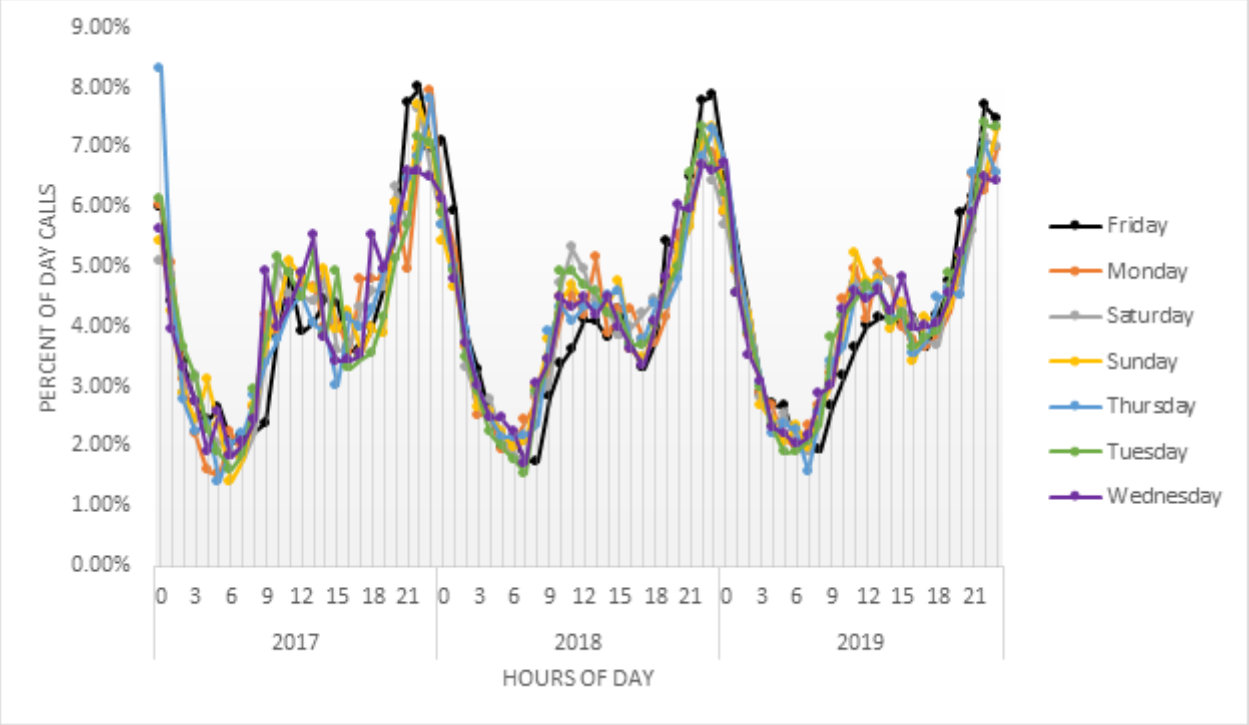


Figure 4

Frequency distribution of cardiovascular-related emergency calls in the city of Mashhad in 2017-2019

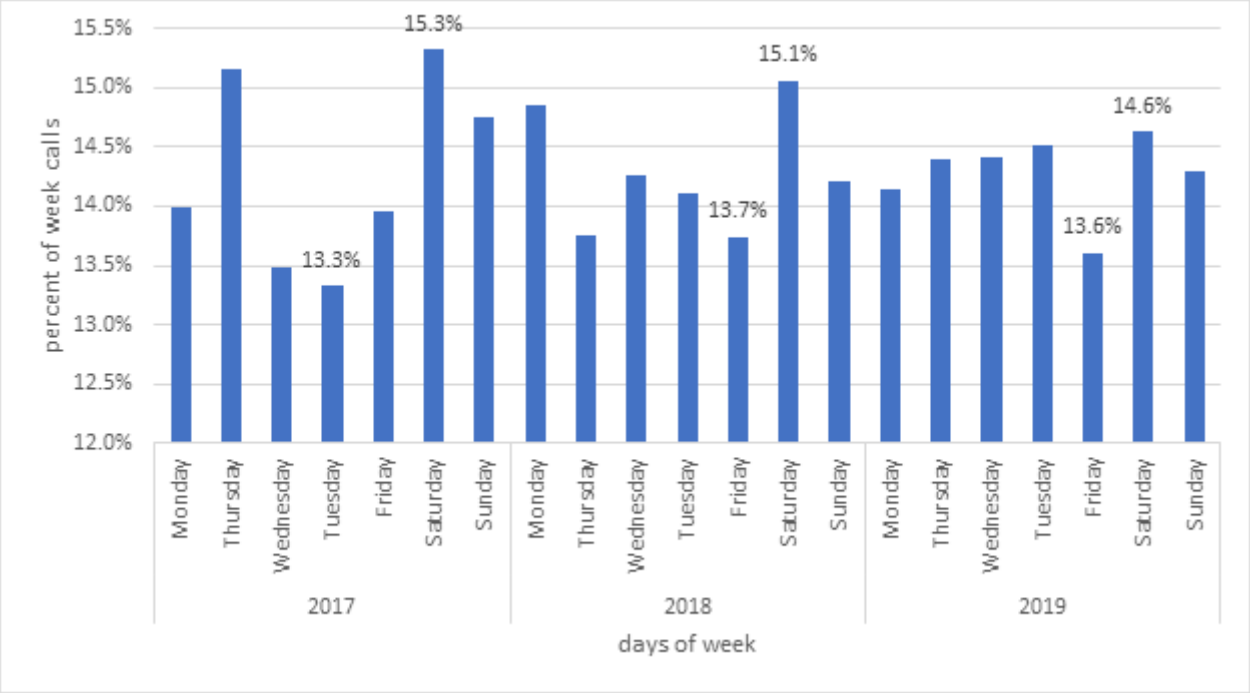


Figure 5

Frequency distribution of cardiovascular-related emergency calls in the days of the week in the city of Mashhad in 2017-2019

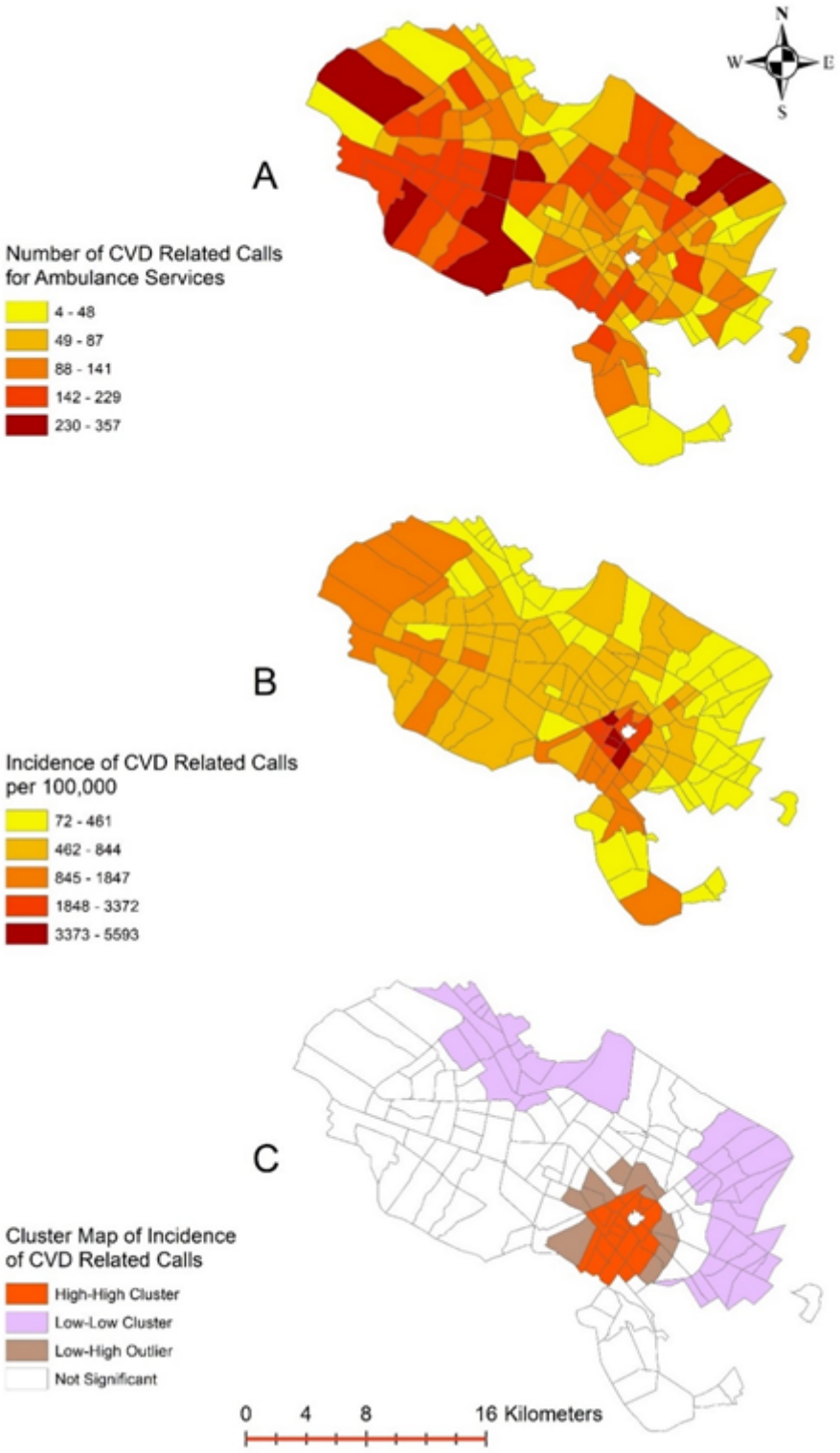


Figure 6

Frequency distribution of cardiovascular-related emergency calls in the days of the week in the city of Mashhad in 2017-2019

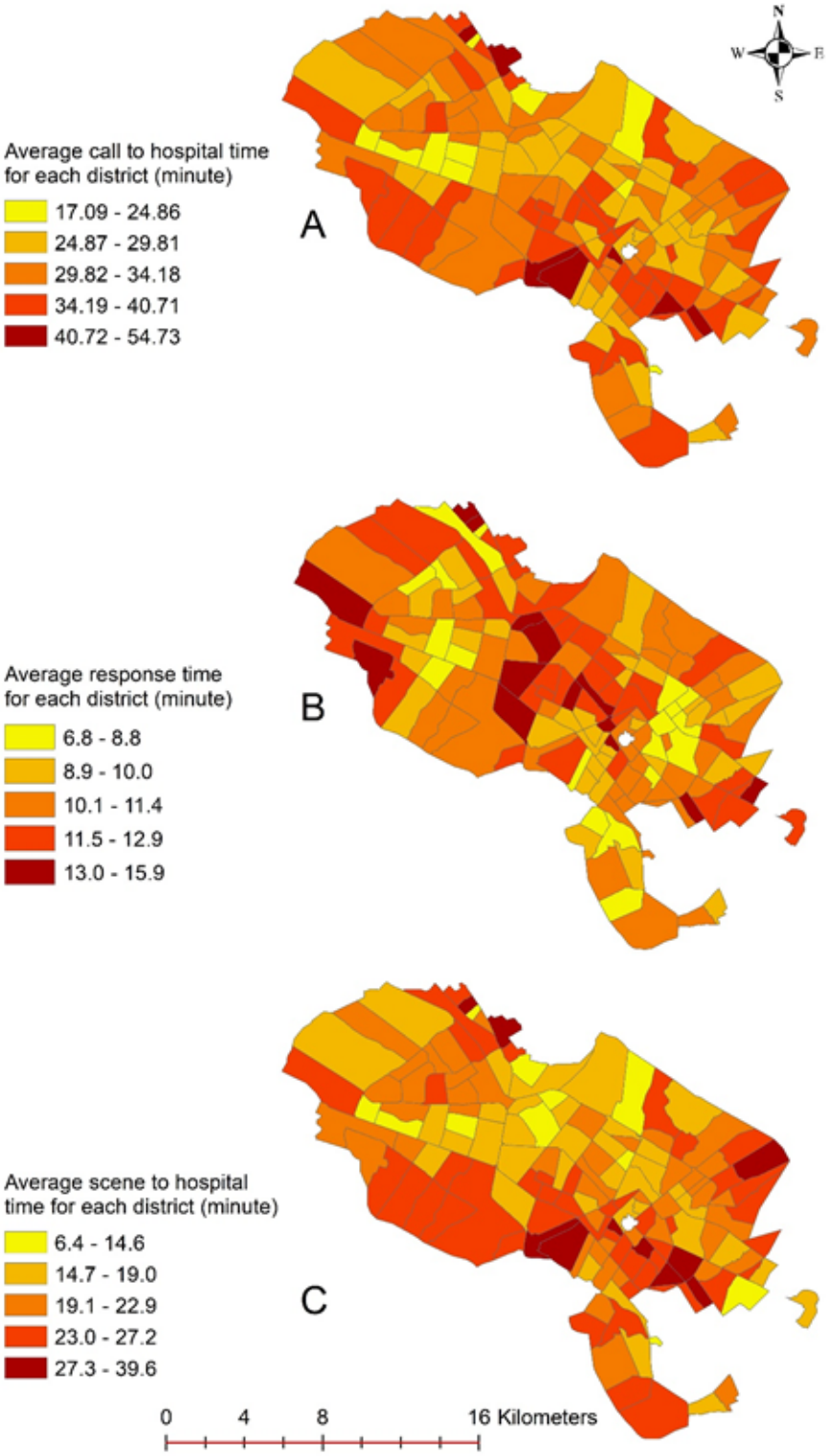


Figure 7

Call to hospital time, response time, and scene to hospital time map of emergency medical calls related to cardiovascular problems in city of Mashhad between 2017 and 2019

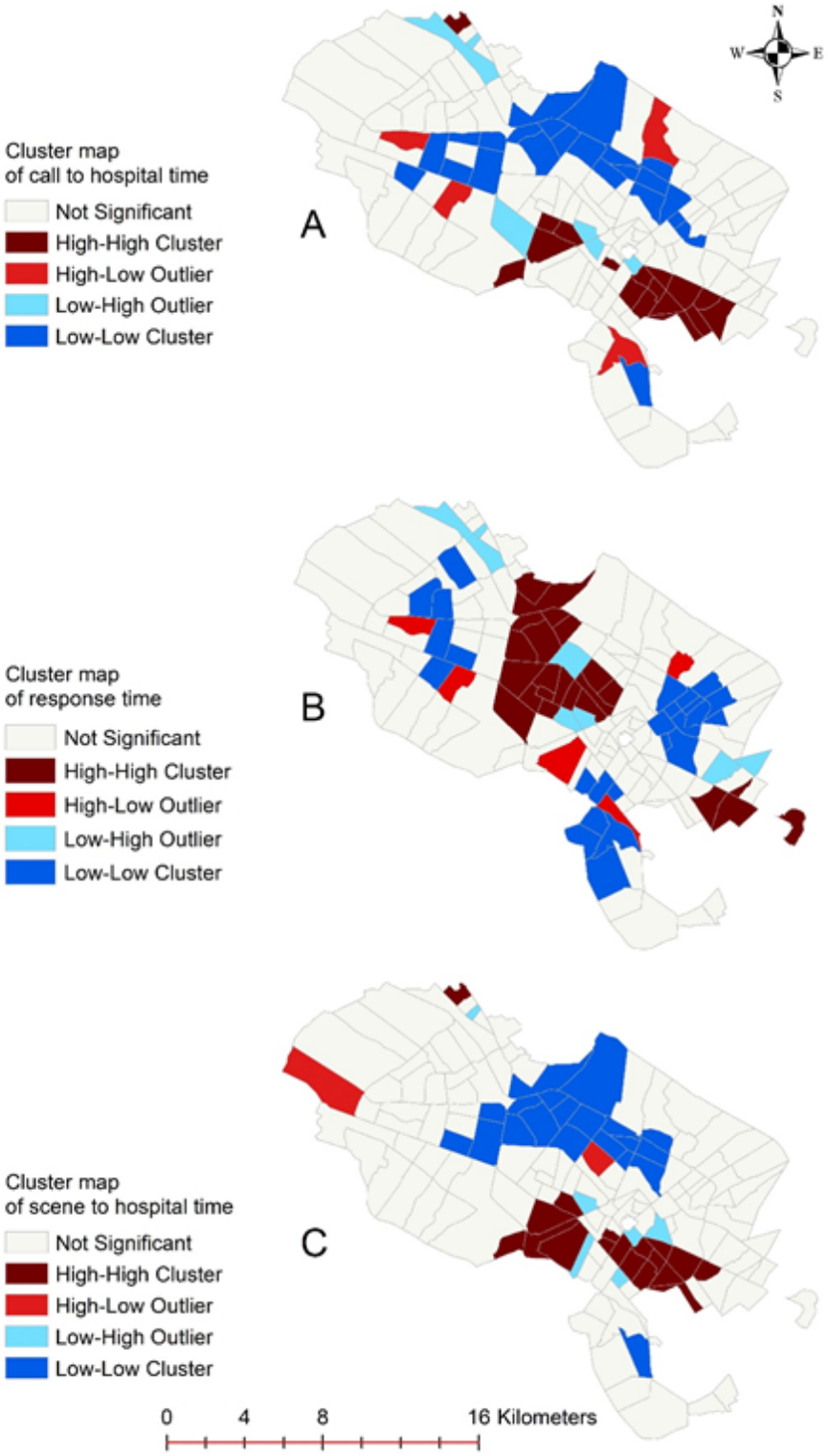


Figure 8

Call to hospital time, response time, and scene to hospital time cluster map of emergency medical calls related to cardiovascular problems in city of Mashhad between 2017 and 2019

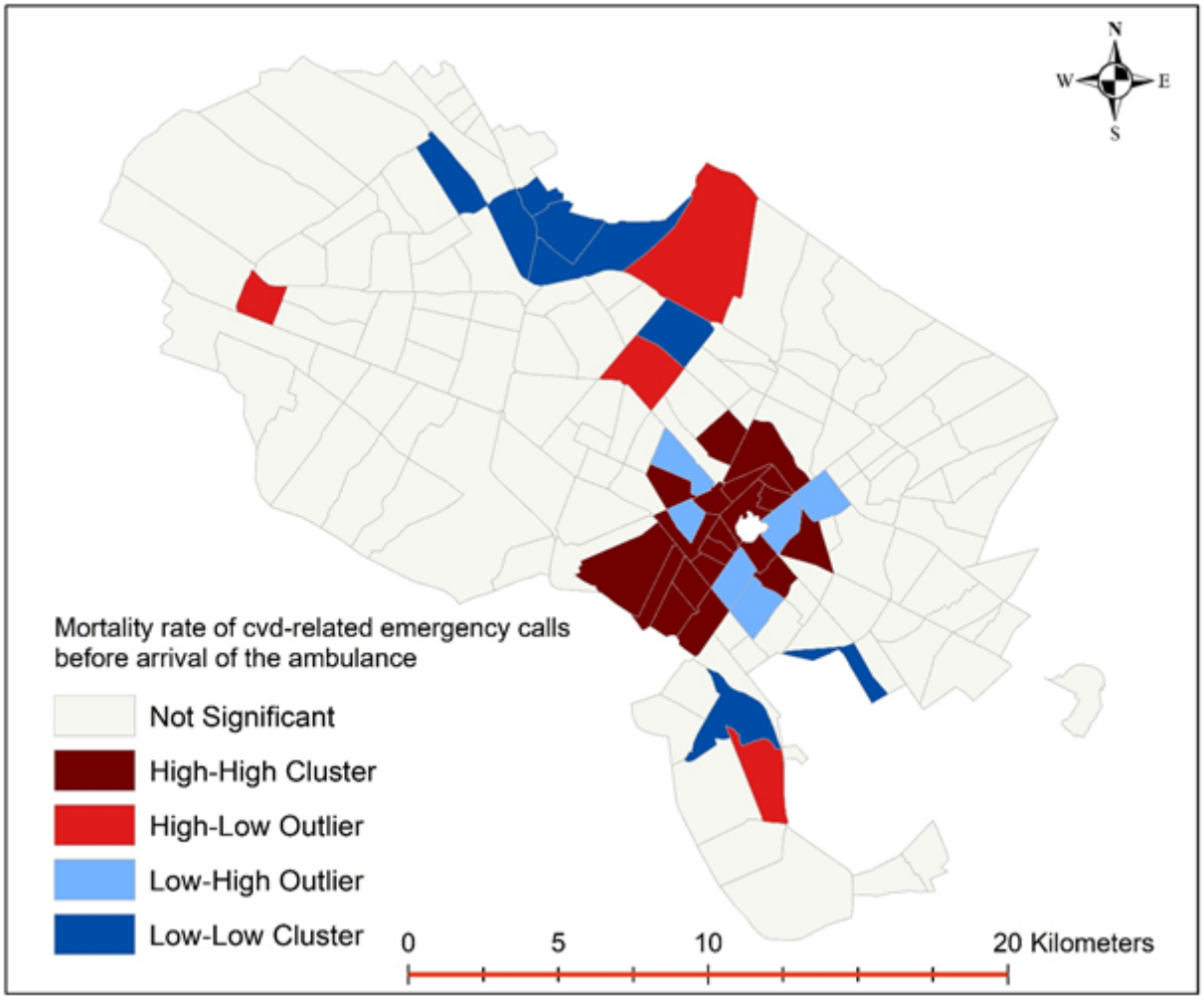


Figure 9

Mortality cluster map of CVD-related emergency calls before arrival of the ambulance to the patient location