SPATIAL ANALYSIS FOR THE IDENTIFICATION OF HIGH-RISK LOCATIONS OF ROAD ACCIDENTS WITH PEDESTRIAN FATALITIES IN LAHORE

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ABSTRACT: Lahore is facing a serious road safety threat due to the increase in road accidents and pedestrians are significantly exposed to the risk of injuries and fatalities. This paper intends to explore the high-risk accident locations with most pedestrian fatalities in Lahore which allows to specifically improve the pedestrian safety. In this research, 702 accidents involving pedestrian fatalities from 2012 to 2017 have been analyzed to determine the trends of pedestrian accidents in Lahore and learn the accident dense areas. These trends are spatially analyzed using Kernel Density Estimation (KDE), an application available in Geographic Information System (GIS), to identify the high-risk locations for pedestrians. The results reveal that most accidents occurred during the peak traffic hours faced largely by males and car is most used vehicle type with reckless driving as the main cause of the pedestrian accidents. The KDE analysis highlighted the high-risk locations for pedestrians which are considered busiest in the city accommodating large traffic volume. Pedestrian safety at these locations can be improved by the enforcement of traffic rules and provision of pedestrian infrastructure and education.

Key words: high-risk locations, hotspots, pedestrian fatalities, road accidents, GIS, kernel density estimation.

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INTRODUCTION

Road safety is a vital global concern which may trigger the public health crisis of road traffic injuries and deaths if not addressed appropriately (Peden *et al.*, 2004). The development of modern transportation systems has led to an increase in the road traffic accidents resulting not only in injuries and loss of lives but causing a major financial threat to the nations (Kazmi and Zubair, 2014; Zia *et al.*, 2014). Road traffic accidents account for nearly 1.25 million fatalities whereas the number of people injured due to these accidents is 50 million per annum around the globe. These estimates indicate that traffic injury is the ninth leading cause of deaths worldwide and is expected to become the seventh by 2030. Globally, 90% of the road traffic deaths take place in low and middle income countries which have only 54% of the world's registered vehicles. The pedestrians (22%), cyclists (4%) and motor cyclists (23%), known as the vulnerable road users, become the target of nearly 50% of such road traffic deaths worldwide (WHO, 2015). Pedestrian safety, therefore, is one of the key road safety concerns as estimates show that around 270,000 pedestrians were killed in 2010 due to road traffic accidents globally. Older pedestrians are more vulnerable in high income countries whereas in low and middle income countries, younger pedestrians are more exposed to deaths and injuries (WHO, 2010).

Pakistan is one of the countries which hold the world's worst records in traffic safety (Zia *et al.*, 2014; Haider and Badami, 2004). The overgrowing population, industrial development and rapid urbanization has exerted extensive burden on the transport system, particularly on the road network, resulting in increased risk of traffic accidents (Arif *et al.*, 2015). The fatality rate recorded in Pakistan due to road traffic injuries is 14.2 per 100,000 population (WHO, 2015). The epidemic emergence of the road traffic accidents in Pakistan over the past years is largely harming the most productive age group of 15-44 years old (Zubair and Kazmi, 2013). The economic burden faced by Pakistan due to road traffic accidents is estimated to be more than 100 billion rupees (Kazmi and Zubair, 2014). Despite the serious nature of road traffic accidents and the resultant losses, there is limited research carried out regarding road safety in Pakistan (Ahmed, 2007).

Lahore, the 2nd largest city of Pakistan and 35th in the world (World's Largest Cities, 2016), is facing a serious road safety threat due to the increase in road traffic accidents. The road accidents have resulted in the deaths of 426, 328, and 308 people in the year 2017, 2016 and 2015 respectively. Records of traffic authorities show that the traffic accidents in the provincial capital have resulted in 45,094 accidents and 51,000 injured people in 2017, 45,094 accidents and 46,246 injured people in 2016 and 46,268 accidents and 49,025 injured people in 2015. Most of the accidents in Lahore during 2017 were caused

due to the negligence of drivers, rash and underage driving. Other reasons include signal violation and negligence of rickshaw drivers (Shahzad, 2016; Randhawa, 2017).

The rise in pedestrian deaths and injuries, due to road traffic accidents, emphasizes the need to understand the problem thoroughly at local and national levels (WHO, 2010). The occurrence of road traffic accidents is mainly caused by human errors and negligence of the drivers or pedestrians. Therefore, the use of adequate solutions such as appropriate traffic control devices, sound design of roads and active involvement of traffic police can help reducing accident probability and severity. The effectiveness of these solutions, however, depends on the identification and analysis of traffic accident locations and timings (Kumar and Rao, 2014). Geo-spatial methods are helpful for analyzing distribution of accidents as non-random spatial-temporal pattern of accidents needs to be carefully examined (Prasannakumar *et al.,* 2011; Shafabakhsh *et al.,* 2017; Aghajani *et al.,* 2017).

Geographic Information System (GIS) is one of the most effective tools for spatial analysis (Satria and Castro, 2016). GIS helps understanding road traffic accident patterns in better ways by combining the spatial and statistical data (Choudhary *et al.,* 2015). It is widely used by traffic departments for the analysis of accidents and the identification of hotspots (Aghajani *et al.,* 2017; Prasannakumar *et al.,* 2011). These hotspots are road sections having a higher rate of traffic accidents compared to other similar locations (Shafabakhsh *et al.,* 2017). The hotspots are also termed as high-risk locations, hazardous locations, black spots, priority investment locations, collision-prone locations, or dangerous sites (Thakali *et al.,* 2015). The hotspots for pedestrians indicate all locations where road traffic accidents involving pedestrian deaths and injuries take place. The analysis of hotspots helps the decision makers reduce the risk of road accidents by adopting effective and necessary measures at those locations (Aghajani *et al.,* 2017).

The identification of the high-risk locations where most pedestrians are killed due to road traffic accidents is the first step in improving the pedestrian safety (Yao and Loo, 2012). The main objective of this paper is to identify the high-risk locations in Lahore with maximum number of pedestrian fatalities due to road accidents. The modelling of real accident locations in GIS can help in the identification of the vulnerable areas and development of solutions to curb accident occurrences (Prasannakumar *et al.,* 2011). Such analysis can facilitate the planners to understand the nature of the problem and propose better road design, engineering, management, awareness and training solutions while GIS can help in the development of remedial measures in a short time (Yohannes and Minale, 2015). As the pedestrians are highly susceptible to road traffic accidents in Lahore (Ahmad, 2016), pedestrian safety is one of the most important concerns and spatial analysis of road traffic accidents is very important for traffic police department as well as planners and engineers.

MATERIALS AND METHODS

The fatal pedestrian accidents data from 2012 to 2017 was collected from City Traffic Police Department, Lahore based on officially lodged first information reports (FIRs) and was analyzed using Kernel Density Estimation (KDE) method in ArcGIS 10.2. The gathered accident data was statistically studied to know the patterns and trends of pedestrian accidents in Lahore and included the following information:

- Location details of accident
- Total number of male and female involved in the accident
- Type of vehicle involved in the accidents and its registration number
- Cause of accident
- Time of accident

In order to create the density maps of fatal pedestrian accidents, the digital road map of Lahore was imported in ArcMap. The imported digital map and the data frame of ArcMap were given the common 'projected coordinate' system to bring them to the same scale. This research is carried out using the co-ordinate system of WGS1980 UCS. The accident locations were then marked in GIS by searching these locations in Google Map and by giving X and Y coordinates of each accident (considering all as point features). These accident locations were attributed with detailed information gathered from the traffic police department.

The geo-referenced fatal pedestrian accident points were analyzed using KDE method which is a spatial analysis tool. KDE is a non-parametric method that uses a density estimation technique (Manepalli *et al.,* 2011). As the risk associated with an accident isn't limited to a single point but is scattered around the accident point, KDE helps the researcher to evaluate the risk spread area of accidents which can be defined as an area around a specific cluster with the highest accident risk (Satria and Castro, 2016; Anderson, 2009). Numerous studies have shown that KDE is useful to identify the accident hotspots (Anderson, 2009). The comparison of KDE method with other spatial methods has shown that it is more suitable for identification of hotspots (Lu, 2000).

The KDE method divides the whole study area to a number of square cells. It introduces a smooth circular surface over each point feature assessing the distance from the point to a reference location, known as the bandwidth, based on a mathematical function

(Bačkalić *et al*.,2014). The surface value is maximum at the location of the point and reduces with growing distance from the point, reaching zero at the reference location from the point (Choudhary *et al.,* 2015; ESRI, 2012). Afterwards, the density for each cell is calculated by adding the values of all the overlapping surfaces and the process is repeated for all the square cells (Thakali *et al.,* 2015). The kernel density is calculated using the following equation.

$$f(x,y) = \frac{1}{nh^2}\sum_{i=1}^{n} K\left(\frac{di}{h}\right)$$

Where *f(x,y)* is the estimated value of density at the location *(x,y)*; *n* is the total number of event points (accidents); *h* is the bandwidth; *K* is the kernel density function and *di* is the distance between the event point *i* and the location *(x,y)* (Shafabakhsh *et al*.,2017; Bačkalić *et al*.,2014).

RESULTS AND DISCUSSIONS

The accident data set gathered from the traffic police department based on the FIRs indicated that a total of 702 fatal pedestrian accidents were reported in Lahore from the years 2012 to 2017. The number of fatal pedestrian accidents between the years 2012 and 2017 have been 119, 112, 113, 122, 116, and 120 respectively. The data analysis to know the patterns and trends of pedestrian accidents showed that males were more vulnerable than females as they were involved in 74.36% incidents compared to females who were threatened by 25.64% accidents (Figure-1). The result was consistent with the conclusion of other studies which stated that males were victims of the most road traffic fatalities (Singh, 2017, Arif *et al.,* 2015, Zia *et al.,* 2014, Zubair and Kazmi, 2013; Raza *et al.,* 2013).

The results showed that different vehicles were involved in fatal pedestrian accidents. Cars were involved in most of the traffic accidents (30.63%) followed by motor cycles (9.69%). Cars and motorcycles are common means of intra-city transportation in Lahore. However, poor maintenance and safety measures often lead to fatal accidents. Heavy trucks, buses, rickshaws and tractors were involved in about 8.97%, 5.70%, 5.41% and 6.55% of all accidents respectively. Wagons and pickups were involved in about 5.70% and 5.84% of all accidents respectively whereas accidents with cranes and coasters resulted in 1.14% and 1.57% fatalities respectively. Others (including ambulances, carry dabbas, dallas, mazdas, oil tankers, qingchis, Toyota hiaces and trailers) and unknown vehicles were involved in about 18.80% of all accidents (Figure-2). The result was consistent with other studies which showed that cars were the most actively involved vehicles in pedestrian accidents (Ali *et al.,* 2018; Arif *et al.,* 2015).

It was evident from the results that most of the pedestrian fatalities were attributed to rash/negligent driving. Other reasons contributing to pedestrian fatalities included over speeding and one-wheeling. The results had similarities with findings of the other studies which indicated rash driving and over-speeding as the main reason behind traffic accidents and deaths (Singh, 2017; Arif *et al.,* 2015; Zia *et al.,* 2014; Bachani *et al.,* 2012).

The results revealed that pedestrian accidents occurred during all times of the day, however there were peak times when the number of fatalities was particularly high. The result showed that the greatest number of pedestrian accidents (36.04%) occurred during 12:00 to 18:00. The percentage of pedestrian accidents from 18:00 to midnight and during 06:00 to 12:00 was 32.76% and 21.23% respectively. The frequency of pedestrian accidents from midnight to 06:00 was quite lower (9.97%) than other times of the day (Figure-3). Thus, it was concluded that the pedestrian accidents mostly took place from 12:00 to midnight. The result was consistent with other studies which indicated that most of the accidents occurred during peak traffic hours (Singh, 2017; Arif *et al.,* 2015; Zia *et al.,* 2014). It is evident that an increase in the commercial, educational and office activities particularly during the rush hours of traffic was the main reason behind more fatalities.

After analyzing the patterns and trends of fatal pedestrian accidents, spatial analysis was carried out in GIS to find out the high-risk locations for pedestrians. A total of 702 pedestrian accident locations were digitized as point features on the Lahore map (Figure-4).

In order to analyze spatial accident data using KDE method, the values of the bandwidth and cell size must be selected according to extent of the study area and the number of accidents (Kaygisiz *et al.,* 2015). It is essential to apply different variants regarding bandwidth and cell size to arrive on the optimum result (Bačkalić *et al.,* 2014). Therefore, keeping in view the number of accident points and study area, the values of bandwidth and cell size were carefully decided. In this research, 1000 m bandwidth and cell size of 20 m was applied. Numerous studies carried out in the past have used different bandwidth values (Thakali *et al.,* 2015 used 400 m and 800 m, Kaygisiz *et al.,* 2015 used 700 m and Bačkalić *et al.,* 2014 used 250 m). Similarly, pervious researchers have experimented with different cell sizes which differ from one research to another (Thakali *et al.,* 2015 used 400 m, Kaygisiz *et al.,* 2015 used 40 m and Bačkalić *et al.,* 2014 used 25 m).

By the application of KDE method to the total number of accidents (*n*=702), it was convenient to find out the high-risk locations in Lahore where most pedestrian fatalities had occurred in the past few years. The output of KDE was presented in a raster format consisting of a grid of cells locating the high-risk

accident locations for pedestrians by clusters (Figure-5). The magenta shade represented the locations with a lower accident density, while red shade indicated locations characterized by the highest accident density. The colour classification helps to clearly visualize the risk locations for pedestrians, thus, guiding the planners and engineers to plan the effective road safety measures (Thakali *et al.*, 2015).

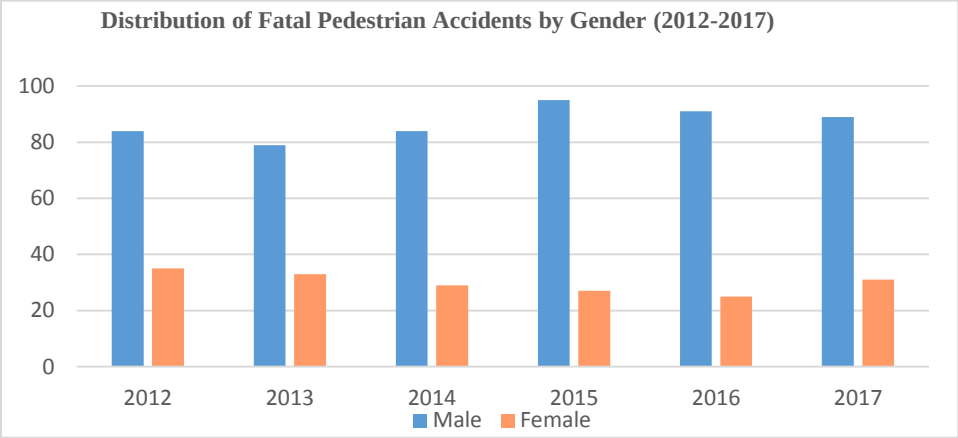

Figure-1: Distribution of Fatal Pedestrian Accidents by Gender (2012-2017)

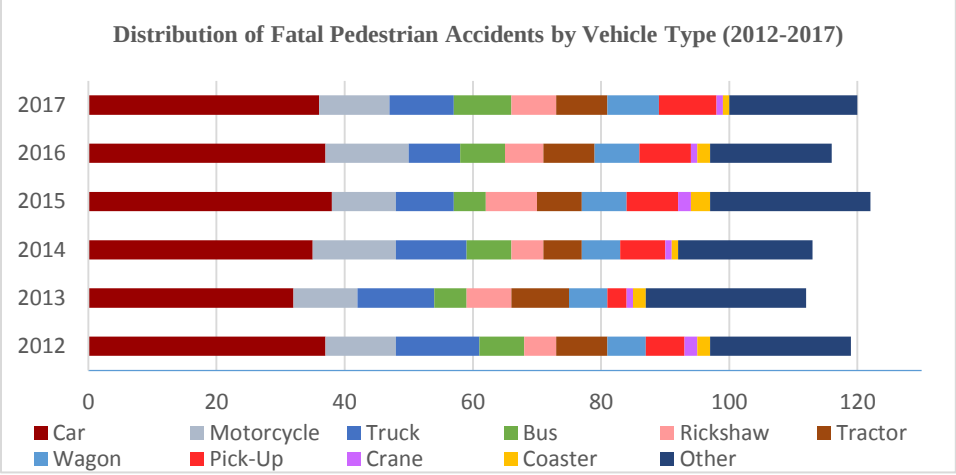

Figure-2: Distribution of Fatal Pedestrian Accidents by Vehicle Type (2012-2017)

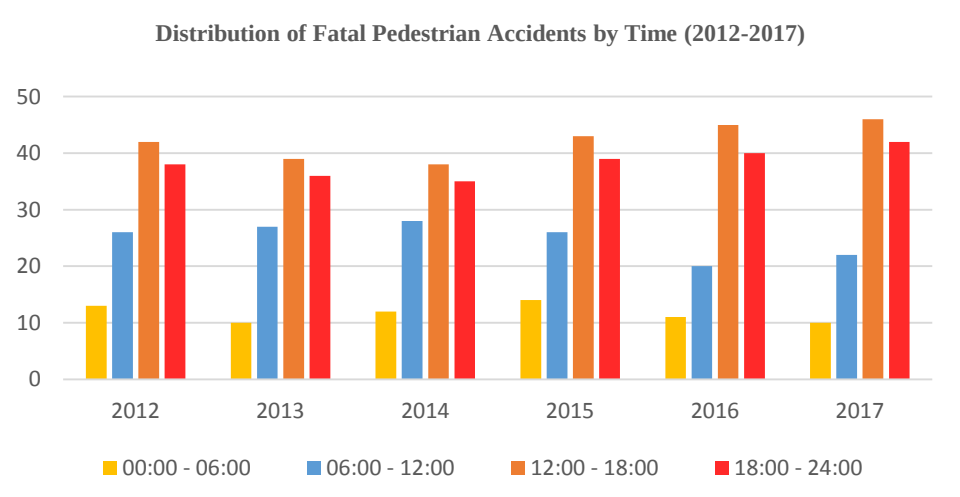

Figure-3: Distribution of Fatal Pedestrian Accidents by Time (2012-2017)

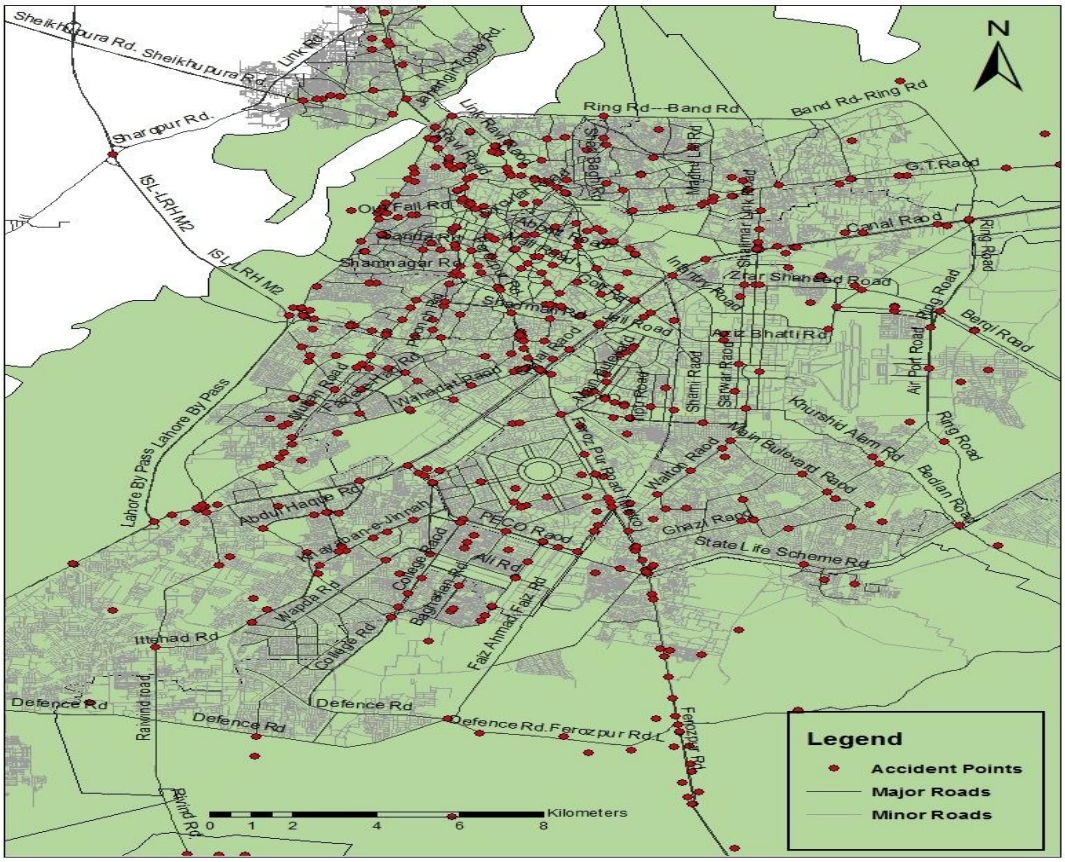

Figure-4: Fatal Pedestrian Accident Locations marked on Lahore Map

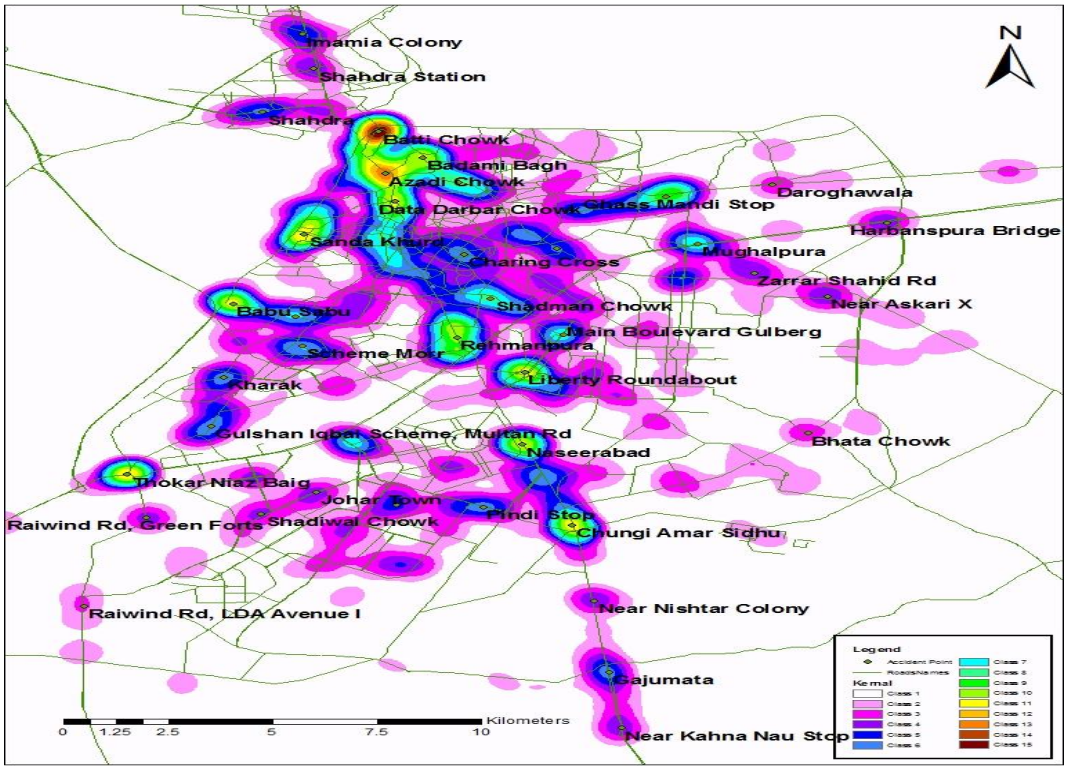

Figure-5: High-risk Accident Locations for Pedestrians

The identified high-risk locations included Batti Chowk, Azadi Chowk, Badami Bagh Bus Stand, Data Darbar Chowk, Sanda Khurd (near Chohan Road), Rehmanpura (near Ichra), Liberty Roundabout, Babu Sabu, Chungi Amar Sidhu, Naseerabad (near Gulab Devi Hospital) and Thokar Niaz Baig. These locations are considered busiest in the city with the traffic all day long. Batti Chowk, Azadi Chowk, Babu Sabu and Thokar Niaz Baig are considered the main gateways to Lahore city accommodating the high city traffic volume along with the intercity traffic. The areas surrounding the Badami Bagh Bus Stand involve the frequent movement of heavy traffic as the bus stand caters the intercity travel buses for almost all the cities of Punjab, and most cities of Sindh, Khyber Pakhtunkhwa and Baluchistan. The areas of Rehmanpura (Ichhra) and Liberty Roundabout, considered as the major commercial hubs of the city, remain busy daily mainly due to existence of shopping complexes. Other identified locations are also highly congested inner-city areas where the land use is mainly commercial and also has some public buildings resulting in high traffic volume daily. The pedestrians in all these areas face an exposure to the intense high speed urban traffic.

The high percentage of pedestrian fatalities is instigated due to numerous factors. The absence of pedestrian bridges or the lack of people's will to use the bridges, if available, force people to cross the busy roads along with fast moving traffic. The violations made by the drivers regarding right of way for pedestrians also contribute to the human loss. Other significant factors include unawareness of traffic rules and signals, carelessness by drivers and pedestrians, over speeding by drivers, the limited use of designated infrastructure such as footpaths and zebra crossings, usage of mobile phones on roads and poor lighting arrangements on roads. These factors have been indicated by many other studies (Ali *et al.,* 2018; Arif *et al.,* 2015; Zia *et al.,* 2014).

The widespread issue of pedestrian fatalities in the city can be addressed by regulating the pedestrian usage of the road space. Provision of essential physical infrastructure such as overpasses, underpasses and signalized zebra crossing, where required, and encouraging its usage is imperative for pedestrian safety. The safe pedestrian movement can also be ensured by removal of the encroachments from the footpaths and provision of warning signs. Implementation of modern intelligent transport system (ITS) applications for the safe movement of pedestrians at intersections and other locations is also needed nowadays. It is also vital to regulate the drivers' behavior by constructing a well-planned road network and rigorously enforcing the law related to control over-speeding and careless driving. The media campaigns to increase public awareness about road safety can also help greatly for ensuring pedestrian safety.

Conclusion: It was concluded that male pedestrians were involved in more fatalities due to accidents as compared to females. Rash driving was the leading cause of the accidents while car was the mostly involved vehicle in these accidents. Majority of the accidents occurred during the peak traffic hours *i.e.* 12:00 p.m. to midnight when the commercial, educational and office activities take place. Detailed future analysis of road and pedestrian infrastructure and traffic characteristics at the identified locations may help the officials in planning measures to improve the traffic flow and pedestrian safety.

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