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Traffic Accidents in Bahrain: A Statistical and Spatial GIS-based Analysis

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Abstract. GIS provides an efficient tool for the analysis of traffic accidents. It relates accidents as place-based events to urban planning and spatial organization of cities and roads network. This study aims at creating a GIS database of accidents data that was collected from the General Traffic Department of the Ministry of Interior (Kingdom of Bahrain) for the years 2000-2004 and analyzing it in relation to the different available layers of the territory. The method of analysis involves two aspects: mapping techniques and spatial analysis (ARCGIS 9) on the one hand, and statistical methods (Excel and Access/Windows) on the other. Results of statistical analysis are categorized, commented and displayed according to time, drivers' identity and causes. Spatial analysis consists of detecting, through the digital map of accidents, the pattern of distribution with regards to urban settlements and roads network, blocks and urban areas and red spots. Both parts of the analysis allow investigations into the trends of accidents in Bahrain in relation to the increasing motorization rate, help identify the deficient areas in terms of roads design and urban planning and detect the major reasons behind the accidents whether or not they are related to space. They also permit forecasting the accident trends given different scenarios of the future such as increase in motorization, urban sprawl, etc. The results would be of benefit to several public agencies such as the Ministry of Housing and Works, Ministry of Interior, Ministry of Health and the Ministry of Municipalities.

Introduction

Traffic accidents are a worldwide problem that cause the death of nearly one million people per year and result in permanent disabilities among at least another 10 million (Abdalla, 2002: p. 483; Murray and Lopez, 1997; Parry, 2004: p. 346). According to the World Health Organization (WHO), traffic accidents is currently the 7th leading cause of mortality and might rise to be the third by the year 2020 (Radwan, 2004). In addition to human lives and injuries, accidents also cause considerable property losses and time delays (Parry, 2004: p. 347). In Bahrain, as in all the Gulf countries, the increase of motorization, with the absence of reliable public transport, is the potential explanation for the increase in road traffic accidents. The vehicle population in Bahrain has increased from 184,000 in 1997 to 369,000 in 2007 (General Directorate of Traffic, 1997, 2007). Despite the high standards of the road networks that have been built in accordance with high international norms, as they have mostly been developed during the last 30 years, accident rates in the Gulf Countries show alarming figures when compared to many developed countries. The fatality rates per 100,000 population in Bahrain is 12.3, in Kuwait it is 17.2, in UAE it is 20.0, in Qatar it is 22.7, in Saudi Arabia it is 23.0, and in Oman it is 35.0. The fatality rates in the Netherlands, Norway, Sweden, Singapore, and UK are less than 5.5 (Al-Madani, 2008). The UAE Ministry of Planning claims one and a half billion dollars due to traffic accidents in the UAE (Al-Madani, 2006). That in Kuwait is around two billion dollars. The insurance companies in Bahrain claimed over 50 million dollars, in 2002, as their direct cost of traffic accidents (Al-Madani, 2006).

Road infrastructure is always given priority in urban planning and is often designed prior to housing and many other urban developments. However, this priority is not in favor to pedestrians when compared to the motorists; as the provided facilities do not fairly support pedestrian safety. It is assumed that most of the people can get around by cars rather than on foot (Abdalla, 2002: p. 489), even in the city centers. Consequently, human errors, due to ignorance of traffic rules and regulations (Abdalla,

2002: p. 485), over-speeding, differential speed, aggressive driving, rank among the top causes of traffic accidents' injuries.

The life styles in the Gulf Countries are characterized by the high gross domestic products (GDP) and per capita incomes that grew rapidly during the last 30 years following the booms in oil prices in 1974, 1980 and 1990/1991 and now (El-Sadig *et al.*, 2002: p. 465). One aspect of this standard is the high car ownership rates and the total dependence on private transportation means. Direct consequences of these are the continuous increase in sub-urbanization, continuous expansion of road networks and substantial increase in traffic. The annual growth rates in the vehicle population in Bahrain, for the period 2003 to 2007, is 7.8% (General Directorate of Traffic, 2003, 2004, 2005, 2006, 2007).

The problem of traffic accidents have attracted extensive research that aimed at increasing traffic safety and reducing the number of victims in case of accidents. For example, El-Sadig *et al.* (2002) have investigated the serious road traffic accidents in the United Arab Emirates. Abdalla (2002) has identified some important risk factors in relation to traffic accident mortality and morbidity in the Emirate of Dubai (UAE). Due to the lack of location-related data, Al-Ghamdi (2003) focused his analysis on accidents that occurred at intersections in Riyadh.

The study of Laapoty (2003) and many others showed that gender has impact on accidents pattern, a fact that is well established in other studies (Abdalla, Raeside and Barker, 1997; Hamdy, Al-Mahmeed and El-Habshy, 1997; Valent *et al.*, 2002: p. 81). Females in general are more safely-oriented and more regulation-respecting drivers than male drivers (Laapoty, 2003: p. 586). It is generally agreed that males have a higher risk of being involved in fatal risks than females (Valent *et al.*, 2002: p. 73).

Much of the researches on traffic accidents evaluate the influence of human related factors, environmental agents and vehicle characteristics on casualties, but less evaluate spatial factors that might affect the pattern of accidents. Spatial and physical characteristics such as population density, land use, road characteristics, planning and design, traffic flow, transport means, and distribution of public facilities could be stated in this context (Noland and Quddus, 2004: p. 974). Kwok *et al.* (2002) showed that the distribution of accidents in Hong Kong is dictated by the location of public facilities and land use mode. The study ended up with a model defining the zones with high accident risks. Kim and Yamashita (2002) found for instance that areas with commercial land use have a higher frequency of accidents due to their volume of movement. Noland and Quddus (2004: p. 974) concluded that there is an association between land use and area deprivation on the one hand, and traffic casualties on the other. Urban zones with high densities such as commercial areas and congested areas have less serious injury accidents than those ones with low densities such as rural areas and residential areas. In other words, the higher the degree of urbanization, the lesser the number of casualties which would be due to the low speed of traffic in dense areas (Noland and Quddus, 2004).

Objectives

The objectives of this study consists of statistical and spatial understanding of the distribution pattern of injury and fatality related accidents all over Bahrain, through statistics and GIS tools, and identifying the major factors behind the accident patterns. Such an analysis is believed to lead the traffic engineers, law enforcement personnel and planners to have more informed and judicious decisions regarding roadway planning, design needs and traffic administration and assignments.

Approach and Methodology

The present study aims to highlight the accident patterns in Bahrain in terms of time, space and human dimensions. Its utility is to increase safety of the road network system and thus serve various public institutions such as Municipalities, General Directorate of Traffic, Ministry of Housing, and Ministry of Public Works, so as to undertake suitable measures for this purpose. Technically, it combines a statistical data on all injury related traffic accidents and a mapping system that is based on GIS for the period between 1999 and 2004. The data will first be analyzed as per their occurrences according to the time of the day, days of the week and months of the year, and then according to the victims sex type, origin, age and rate of involvement in accidents. Then, the accidents were analyzed spatially through superimposing maps of road network of Bahrain to GIS. The technical work that has been done in this study consisted of getting the data from the General Directorate of Traffic in ACCESS format. Layers of road networks in Bahrain were then acquired from the Ministry of Municipalities, whereas those on administrative boundaries, i.e. blocks and governorates, were supplied by the Central Informatics Organization (CIO). Traffic and geometric data were gathered from Ministry of Public Works. The layers were geo-referenced to UTM 84 Zone 39 and then

accidents were added as point's events using the *XY Add Events* instructions of ARC GIS 9.2.

The analysis of accidents as a spatial related phenomenon and thus the use of GIS consists of detecting the impact of location and the characteristics of the physical space on the pattern, nature and periodicity of occurrence of accidents. The depth of the spatial analysis will depend on the availability and relevance of the spatial data. Information such as urban density, zoning and land-use of major urban activities, distribution of facilities over the territory, travel surveys regarding paths and flows, major destinations, motorization rates per urban areas could be of importance to the study that help apply different overlays and investigate the relationships between spatial data and accidents.

In our case, as well as other Gulf Countries such as Dubai (Abdalla, 2002; El-Sadeg *et al.*, 2002) and Riyadh (Al-Ghamdi, 2003), despite the significant number of accidents compared with the universal standards, very few data in relation to space that better help in understanding the phenomenon are available. In the case of Bahrain, the spatial data that could be collected consists of roads layer, administrative boundaries and location of urban areas. The GIS that covers, with the presence of various thematic maps, half of the present study is limited to the locations of accidents on the ground, their relationships with the roads network, and the physical space at four hierarchic scales that are the territory, the arteries, the urban blocks and the hotspots.

Data Gathering

The accidents' data used for the study were gathered from the General Directorate of Traffic in the Kingdom of Bahrain through the Centre for Transport and Road Studies at the University of Bahrain. The General Directorate of Traffic is responsible for investigating all the traffic accidents that occur in the territory of Bahrain. Police are required to attend the accident and report the circumstances in which the accident occurred and to collect the necessary physical evidences from the accident scene that support the investigation process and for the use, in case needed, of court trials. The personal, vehicle and road details, along with the accident description, are reported on the site in a hard copy format. These are then digitized in the database by technicians. For the purpose of security and confidentiality, the General Directorate of Traffic removed some of the sensitive personal and court information from the submitted data. These included victims' names, physical characters of persons, addresses, driving license numbers and photos. The provided data were mainly in Arabic and consisted of the following: all the injury accidents (4,258 rows and 31 columns), the victims (6,617 rows, 6 columns) and the vehicles (7,152 rows and 8 columns). These were specially prepared for this study. A process of translating Arabic terms into English, and codifying the text data was necessary to manipulate the data for the use of GIS tools. However, a lot of information such as the quality of roads, the conditions of the accidents (day/night, wet/dry roads, paved/non-paved roads), type of collision, type of vehicles and number of victims were excluded from this study as it exceeded its scope. The total number of injury related accidents that were reported during the period 1999-2004 totalled to 3,984 cases. The data included 233 fatal accidents, 1,224 serious injury accidents and 2,527 slight injury accidents.

Discussions

This part of the study analyses the accident statistics time wise and personal wise.

Accidents over time, days and months

Statistics show that accidents are distributed evenly among the various days of the week, regardless of the differences in the exposure rate, both in driving mileage and number of trips. On average, each day carried 566 injury accidents for the period under consideration. The least accidents' day is Friday that is the national off-day in Bahrain, whereas Wednesdays and Thursdays have relatively the highest number of accidents with 605 and 592 cases respectively. It is quite interesting to mention that Fridays carry lesser number of trips and vehicular traffic which make it more vulnerable, when accidents per mileage per day is considered, than the rest of the weekdays. Time is also an indicator in the accident pattern over the days. Figure 1 shows that most of the accidents occur during the daytime. Most of the accidents tend to occur during the afternoon, at about the noontime rush, and during early evening and beginning of the night, especially between 4:00 PM - 10:00 PM. The schools end within the former time, i.e. 12:00 PM - 2:00 PM. Similarly, some private sectors break at around 1:00 PM. The latter period is the time when most people get out after the period of siesta. This what we call evening peak. The shifting of the graph to the late afternoon and early night might also be explained by the exhausting state of drivers at the end of the day. As it is clear both periods are among those carrying the highest exposure rates through the day since many people are behind wheels for either work duty or social purposes.

Monthly distribution of accidents (Fig. 2) shows July, August and September to carry the lowest accident frequencies through the year. It keeps increasing during the first term of the year and reaches its peak in March. The average monthly accident frequencies vary slightly during April, May, June, October November and December. The average monthly rate is around 350 injury accidents. The lowest rates could be attributed to the long hot summer holidays where most expatriates and some locals leave Bahrain for at least part of the summer. However, the highest rate in March might probably be explained partly by the good weather that excites people to move and thus increases the exposure rate, i.e. volume of circulation. Furthermore, the GCC traffic weeks take place during March. Nevertheless, the influence of such weeks on accident rates are yet to be investigated.

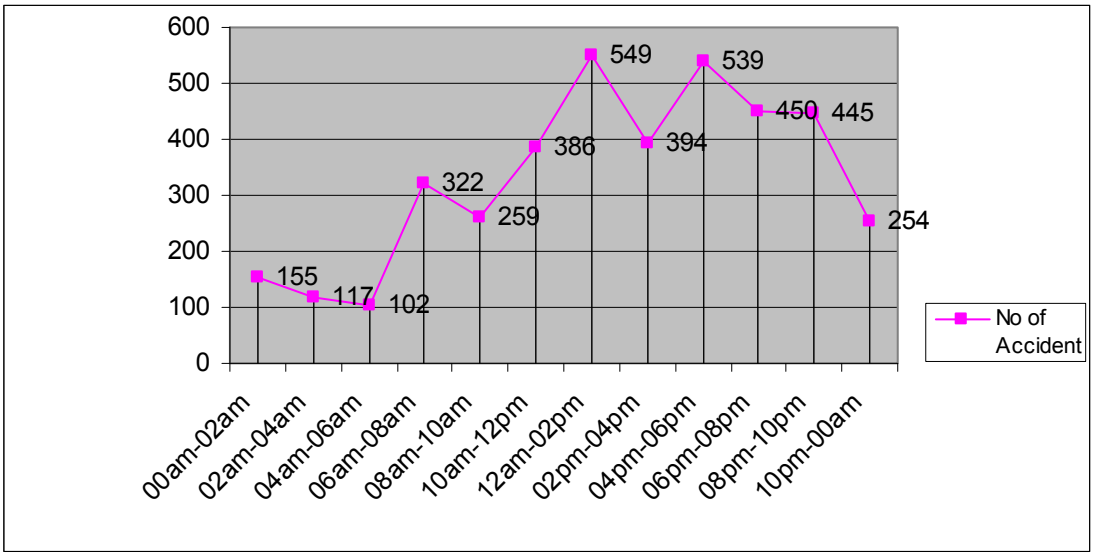

Fig. 1. Accident pattern over the day.

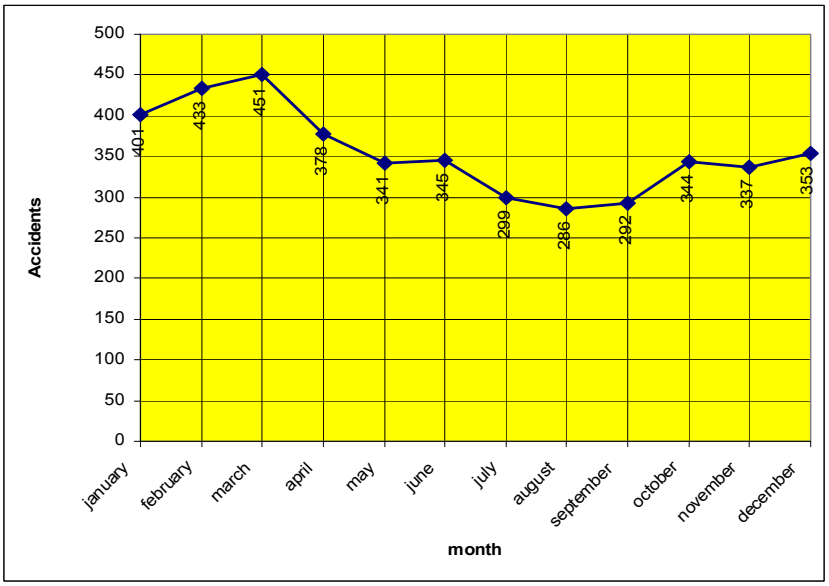

Fig. 2. Accident pattern over the year.

Accidents according to gender

Social norms in Arab societies are generally less motivating to females' mobility. Female drivers' annual mileage is also significantly less than that for the male ones. They make fewer trips than males. Consequently, male drivers are more likely to commit severe accidents than females (Abdalla, 2002: p. 490; Valent *et al.*, 2002: p. 73). However, in Bahrain due to the limited geographic space, this might be less evident than in the other larger Gulf Countries, such as UAE. In Bahrain, it was found that the number of male drivers involved in accidents was 5,748, whereas that of female drivers was only 1,000. This information, however, needs to be correlated to the drivers population according to gender. Though the precise percentage of female drivers, compared with male ones, is yet not available; female drivers are clearly less than male ones. This is simply because 38% of the population are expatriates who are mostly masculine labors. Quantitatively, the female drivers exposure rates are therefore less than that for the male ones.

Accidents according to nationality

Gulf countries are characterized by the heavy presence of expatriates that ranges between 38%, in Bahrain, and over 80%, in the UAE, of the total population, most of them belonging to the working class. While it is of interest to analyze the involvement of expatriates in accidents both globally and nationality, the results should take into account the drivers' population as many expatriates don't drive. From the data, the ratio of accidents committed by the locals is 34.5% of the total number, that is 1,377 cases. It is followed by Indians with 224 cases (6.1%), Pakistanis with 79 cases (2.0%), Saudi Arabians with 68 cases (1.7%), and Bangladeshis with 57 cases (1.4%). Despite the outnumbering of Asians in employment sector, Arab drivers seem to be more involved in accidents with 1,509 cases than Asian counterparts who committed only 377 accidents. These ratios, however, need to be reviewed in the light of the exposure rates of the population categories of the Bahraini society.

Accidents according to age

Ages of victims are represented by the curve (Fig. 3) that is based on five years categories of ages of all victims. It shows clearly that the pattern increases exponentially for categories of ages between 15-55 and stagnates gradually afterwards. This pattern reflects the population structure of the Bahrain society as represented by the pyramid of ages. An exception should be mentioned regarding the ratio of male victims that is 4,443, to female victims that is only 1,708. This exception most probably reflects the social fact that most Gulf females do not drive out but stay at home. Regarding the age of victims, the statistics showed that among 6,301 cases, 1,372 were pedestrians; i.e. 22%, among which 42 % (575 cases) are children under 15 years, and 1.5% of cases were caused by the lack of respect for crossing areas. A further study could explain this phenomenon as it represents the safety level of streets and public facilities such as schools, shopping centers and mosques in urban settlements.

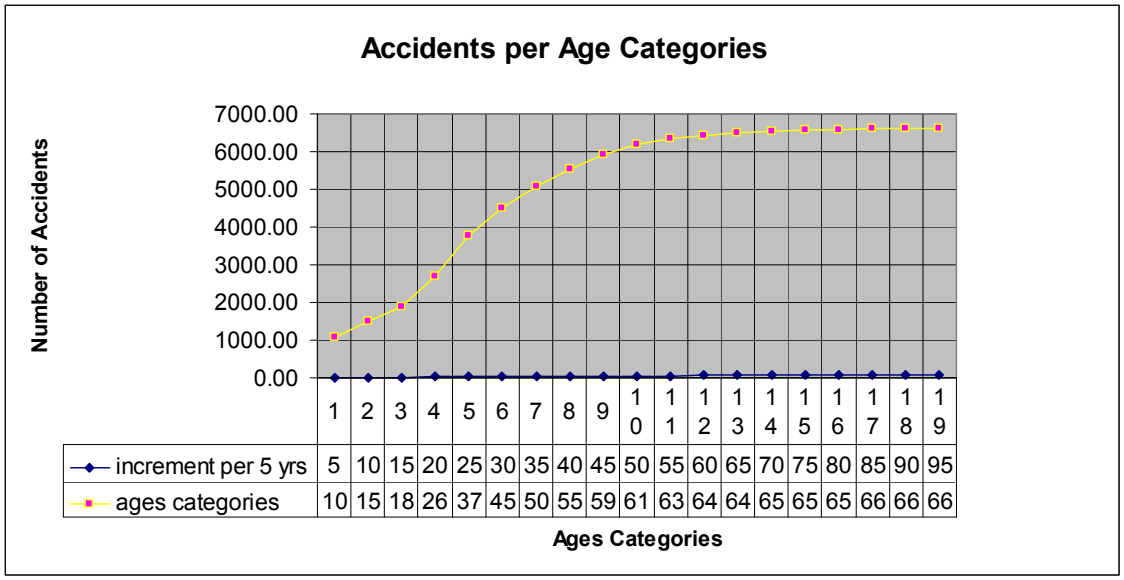

Fig. 3. The relationships between ages of victims and accidents.

The driving experience also showed that the number of accidents in general decreases with the experience. Nearly 40% of cases were committed by people having experience less than 3 years. Within this percentage it was found that drivers having one year and two years experience committed 15% and 14% accidents, respectively. These results partly corroborate that of a similar study conducted in Australia in which young drivers are found to be more generative of accidents than other categories (Lam, 2002: p. 412).

On considering the age of vehicles involved in traffic accidents, statistics showed that there is no clear evidence of relationships between old cars and accident patterns. While the 10-year old cars are the least vehicles causing accidents, 9-year old are found to be the most vehicles involved in accidents. New vehicles having 3 years old were all together involved in 461 accidents, that is 26.6% of total registered cases.

Age of drivers was also found to affect the accidents pattern. For instance, a study that was conducted on Udine, Italy, by Valent *et al.* (2002), found that the old-aged people (over 65) were strongly associated with fatal accidents, whereas drivers of less than 30, had the highest risk of non-fatal injuries. In another study, it was found that the young drivers engaged in distracting behavior or used distraction means while driving such as mobile phone usage, conversation with passengers and, listening to, and handling, radio and recorder, generated more accidents (Lam, 2002: p. 412). In the case of Bahrain, the data under analysis provides a strong relationship between the age of drivers and accidents. It was found that the category of drivers aged between 21-25 have the highest rate of involvement in accidents. The rate of involvement in accidents then decreases gradually with age. It was also found that among the drivers involved in accidents, 90 cases were caused by drivers under 18, i.e. the ones driving without permit. Such results, however, should be considered within the population pyramid structure within which the youth constitutes a large percentage of society (Fig. 4).

Causes of Accidents

According to the General Directorate of Traffic data, there are 35 factors behind the 3,973 recorded accidents among which 706 cases are unknown. Classified according to the number of cases, three categories could be seen; the first one has seven causes that stand behind over 100 cases, the second one has eight causes that stand behind 25-75 cases, and the third has 13 causes that stand behind less than 10 cases. It is evident that the major cause is careless driving and lack of attention as it generates 2,613 cases, that is 65% of the accidents. This factor seems to be common with other Gulf Countries. In the UAE for instance, it was found that the percentage of accidents due to this factor were 54% in 1994 and dropped to 37% in 1995 (El-Sadeg *et al.*, 2002: p. 472). The same findings also apply to Riyadh, Saudi Arabia where most accidents were caused by improper driver behavior (Al-Ghamdi, 2003).

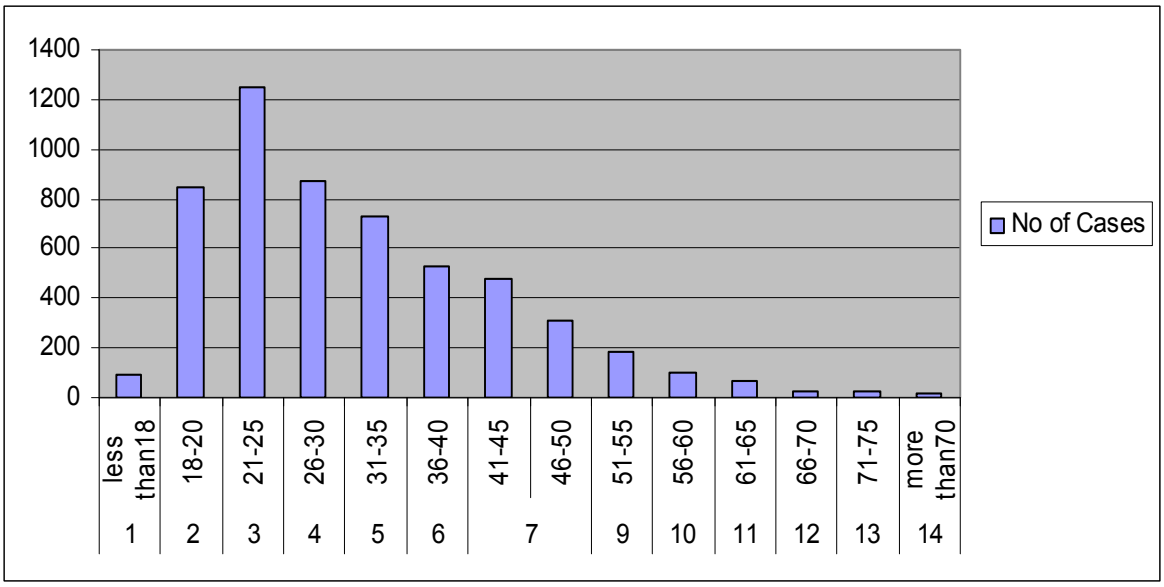

Fig. 4. The relationships between driver's ages and accidents.

The second cause is the over-speeding that generated 4.7% of the accidents and that has the same percentage as in Saudi Arabia. It is, in other words, much less than that of United Arab Emirates in which more than 25% percent of accidents were generated by this cause. Such a major difference needs further investigation and a comparative study.

Being an Islamic Country, alcohol is generally not a major problem as it is forbidden by religion and socially rejected (Abdalla, 2002: p. 484). However, it is the third major cause that stands behind 1.8% of accidents in Bahrain.

People driving without licenses is another factor that generates accidents in Bahrain. Opposite to the table of causes that mentioned only two cases behind accidents that is insignificant, 90 cases were recorded in the second table on vehicles, that is 2.26% of the total accidents. A further investigation is, therefore, required to remove or understand this apparent contradiction. Other personal causes such as failure of respect of priority, lack of distance between cars when driving, lack of precautions when turning right and left, and overtaking caused altogether 5% of accidents.

Affirmative evidence found between mobile phone usage while driving and accidents (Lam, 2002: p. 412) was not possible in the case of Bahrain due to the lack of such information. The few recorded cases, that are only four, may not reflect reality as drivers may not like to declare this cause that is against their cases in court.

Spatially related traffic casualties

The available spatial data for Bahrain consists of the blocks and municipals' boundaries, and the road network over the national territory. Roads hierarchy consists of three categories; the highways, the avenues and the roads. Other general trends as in population, housing, industrial sectors and agriculture lands are also available. However, other vital data such as land-use, urban categories, socio-economic data that characterize each block and many other physical data were not accessible. Traffic volume per major road are used for the consideration of exposure rates to accidents, since no better assessment measures are currently available. Sections below will analyze accidents according to their geographic location.

The general pattern of accidents

There are in total 3,984 located accidents, among which 233 are fatal accidents, 1,224 are serious injury accidents, and 2,527 are slight injury accidents. The pattern of the 3,984 accidents, during 1999 to 2004, over the territory (Fig. 5) shows that they are mostly concentrated in the urban areas in the north and along the major arteries. The results showed that the capital governorate, as expected due to higher population, carries the highest percentage of injury related accidents (1,043 cases; 26%), followed by the northern governorate (956 cases; 24%). The central governorate comes third, out of the total of five governorates, with 785 cases (20%). These major settlements are, therefore, the major clusters of accidents. This concentration of accidents may be interpreted as a consequence of high traffic volume and large number of at-grade intersections. Many of the latter ones are heavily congested. One of the characteristics of traffic in Bahrain and in the Gulf Countries is the heavy reliance on passenger cars and absence of public transport and mass transit system as well as any other mode of transport as sea ferry shuttles. Although congestions reduce accident severity, they also lead to dangerous crossing violations. In other words, the cities carry high pedestrian related accidents (Fig. 6).

Analysis according to arteries

Figure 7 shows a pattern of accidents distribution as per their location classified according to arteries representing highways and major avenues. This is complemented by Table 1 that shows their features that, however, is not directly related to the accidents in this analysis. Statistics showed that around half of the fatal accidents (47%) occurred along these arteries. These are distributed hierarchically in the previous figure. The other half occurred within the cities. The classification of the first 10 arteries in terms of fatalities shows that Sheikh Salman and Isa bin Salman Highways are the most vulnerable ones. They carry 19 and 18 fatalities, during the covered period, respectively. Both are built up to high standards and carry high speed limit of 100 km per hour. This is the highest speed limit allowed in the Kingdom. Geometrically the highways carry three lanes in each direction. Each lane is at least 3.1 m width. Both carry very limited number of at-grade intersections. Isa bin Salman Highway carries the heaviest average daily traffic in the Kingdom (Fig. 7). In the second category come Al-Fatih, Budaiya, Al-Istiqlal and Dry-Dock highways that carry at least two lanes in each direction but they are internal arteries. Lane widths are similar to the earlier ones but with frequent at-grade intersections of various types of control, as roundabouts and traffic signals. The high frequency of fatalities along the former two highways may be interpreted as due to the territorial

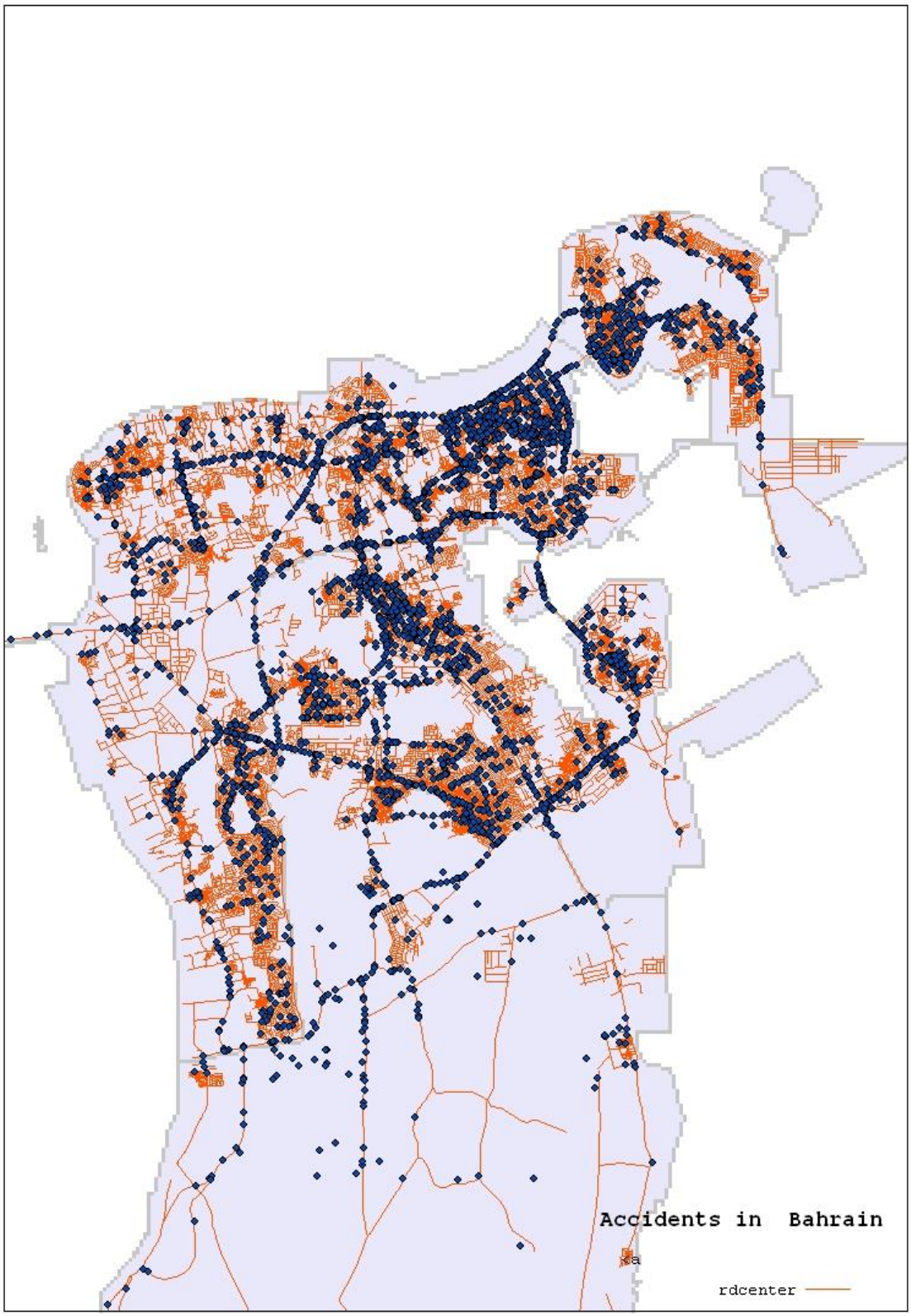

Fig. 5. Accidents pattern in Bahrain.

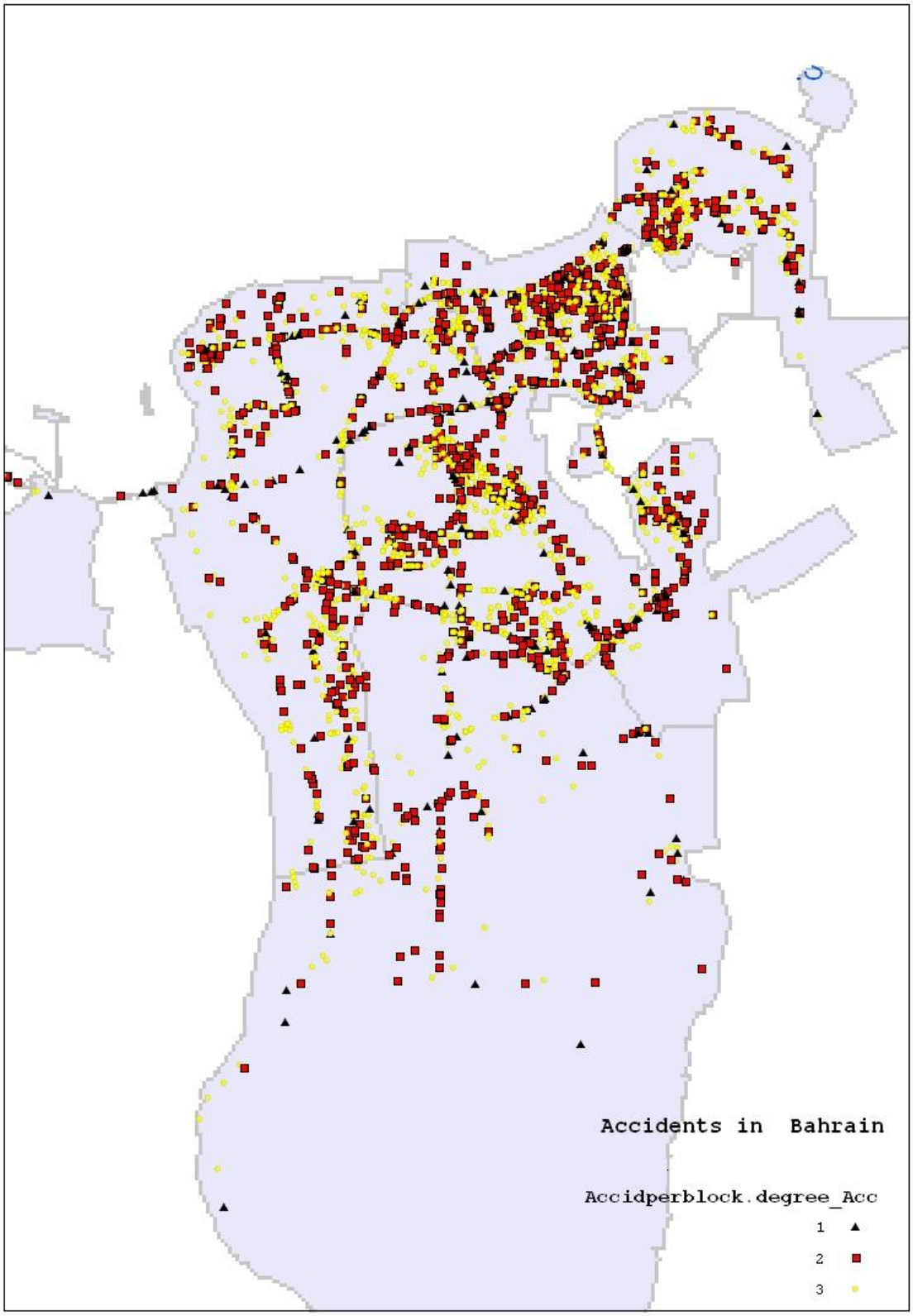

Fig. 6. Accidents pattern per degree of fatality.

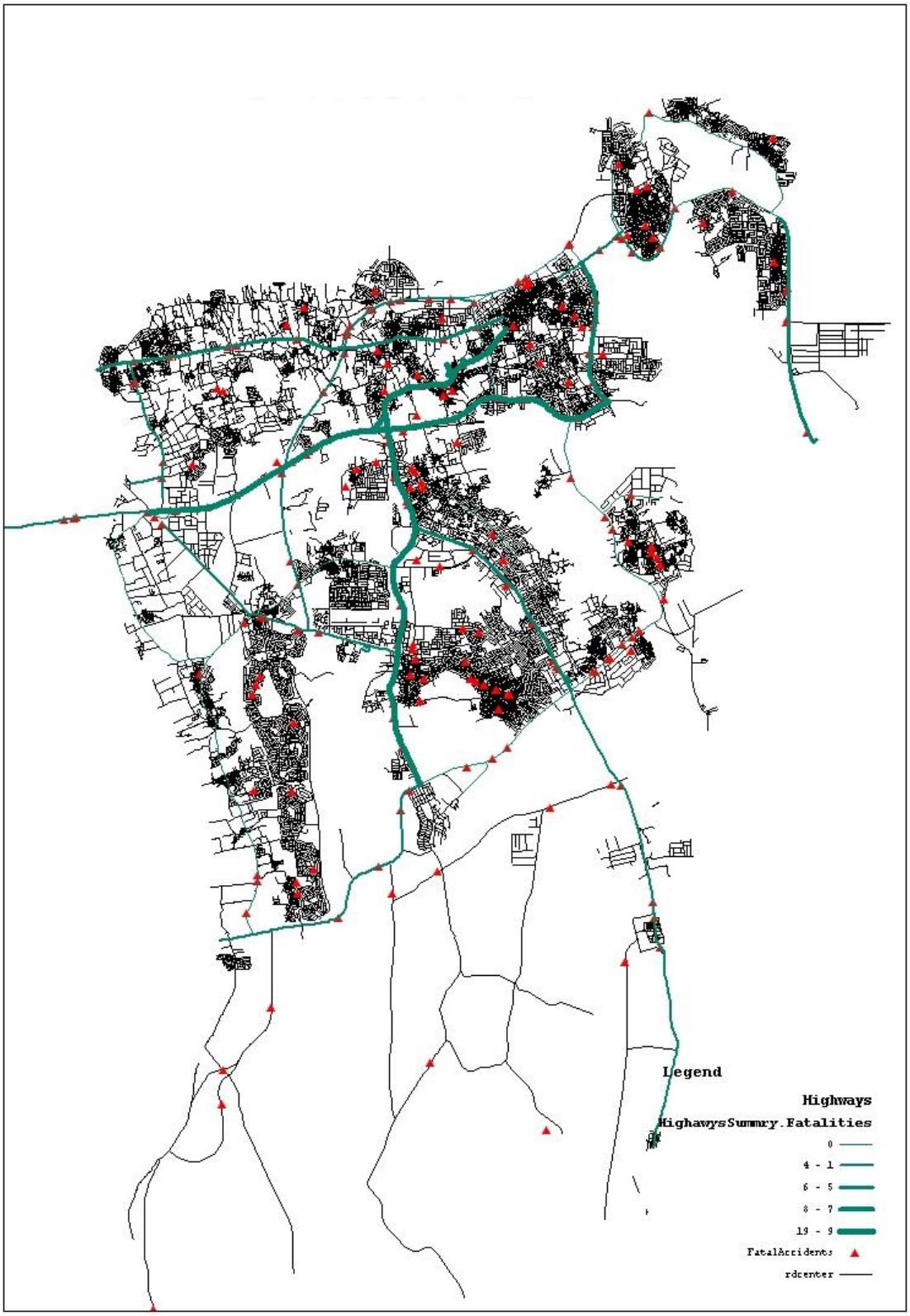

Fig. 7. Hierarchy of roads according to the number of accidents.

Table 1. Physical characteristics of the major roads in Bahrain

#	Highway Name	U k-ph	Lanes Number	Lane Width (m)	Shoulder Width (m)	Others
1	Budaiya	80	4	3.0 - 3.2	0.2 - 0.8	Curbed
2	Sh. Khalifa B. Salman	100	6	3.1 - 3.2	1.8	Barriers
3	Dry Deck	80	4	3.0 - 3.2	1.5 - 2.0	Open/Curbed
4	Al-Fateh	80	6	3.1 - 3.2	0.3	Curbed
5	Sh. Jaber B. Sabah	80	4	3.1 - 3.2	0.3	Curbed
6	Askar	80-100	4	3.1 - 3.2	0.6	Barriers
7	Sh. Salman	80-100	6	3.1 - 3.2	1.8	Mountable Curbs

role of each of the two arteries. Sheikh Salman Highway measures 27 km, which is just under half the length of the Kingdom, and plays a major spine role in Bahrain. It extends north-south and links all major urban concentrations to the main island. Along this axis are also located the two campuses of the national university, the private schools area, military headquarters and accesses to other urban settlements. The second axis measures around 15 km and links the urban pole Manama-Muharraq to Saudi Arabia through King Fahad causeway and is thus the second most busiest artery in Bahrain. Fatalities along these highways might be explained as due to the high speed of cars and the differential speeds between them. It is also important to mention that these highways lack proper pedestrian crossing facilities and crossing prevention facilities, as fences. On the other hand, frequent errant vehicles crossing to the other direction of traffic during accidents, escalating accidents' severities, were observed. This is due to the availability of curbs right after the median shoulder, which gives a jump to errant vehicles to cross over to the other direction. Furthermore, the highways lack proper up-to-date high-tech facilities, as variable sign message systems and incident detectors. The latter increases drivers' vigilance and inform them about any unforgiving incidents ahead and works as awareness tools for foreign drivers.

Analysis according to blocks

On investigating the blocks that carried high rate of accidents, it was found that blocks 302, 304, 318, 319, 321, 346 and 315 have the highest rates of casualties that ranged from 30-51 casualties (Fig. 8). Most of these blocks are located in the core of Manama, whereas a third of these blocks is located along the King Faisal Highway that links Manama with the remaining settlements to Muharraq and the Airport. These blocks are among the densest populated ones in the Kingdom. It is interesting to mention that around one third of the traffic fatalities are pedestrians (General Directorate of Traffic, 1999-2006). Unfortunately, the mode of mobility within the city is in favor of cars at the expense of pedestrians. Furthermore, the cars are not even discouraged from entering the historical city center that has very narrow streets. The condition seems to have worsened after the expansion of the Bab Al-Bahrain old core to the two new other central business districts, namely the diplomatic and Seef areas. However, most of the accidents in these areas are slight injury ones as the speed of cars is relatively low. Block 976 north of Bahrain that comprises University of Bahrain, the Formula 1 racing circuit and other recreational attractions in Sakhair area is also among the highly rated blocks (36 injury accidents). The block carries heavy traffic flow and large portion of the users are young drivers. It is also worth mentioning that these are highly utilized by young drivers.

Defining Clusters

Clustering of accidents is based on the minimum distance between their locations. The created clusters reflect black spots, defined as a zone having high accidents risks (Kwok *et al.*, 2002: p. 394), in the accidents pattern and thus serve to identify the sensitive locations in the road network that needs special attention in terms of engineering solutions and human conducts. Mapping accidents is the first step in determining the number and location of clusters, which was considered through ARC-GIS. Figure 9 shows the location of hotspots over the Bahrain territory. As can be seen from the figure, most hotspots are located along the two major highways discussed earlier. Most of them are also related to intersections, due to high conflict points, that give access from local ramifications to these arteries. Other hotspots could also be identified on the busiest arteries of major urban concentrations such as the end of Hamad Causeway (accessing to Muharraq), Bab Al-Bahrain intersection, north of Hamad town, north of Isa Town, and Riffa.

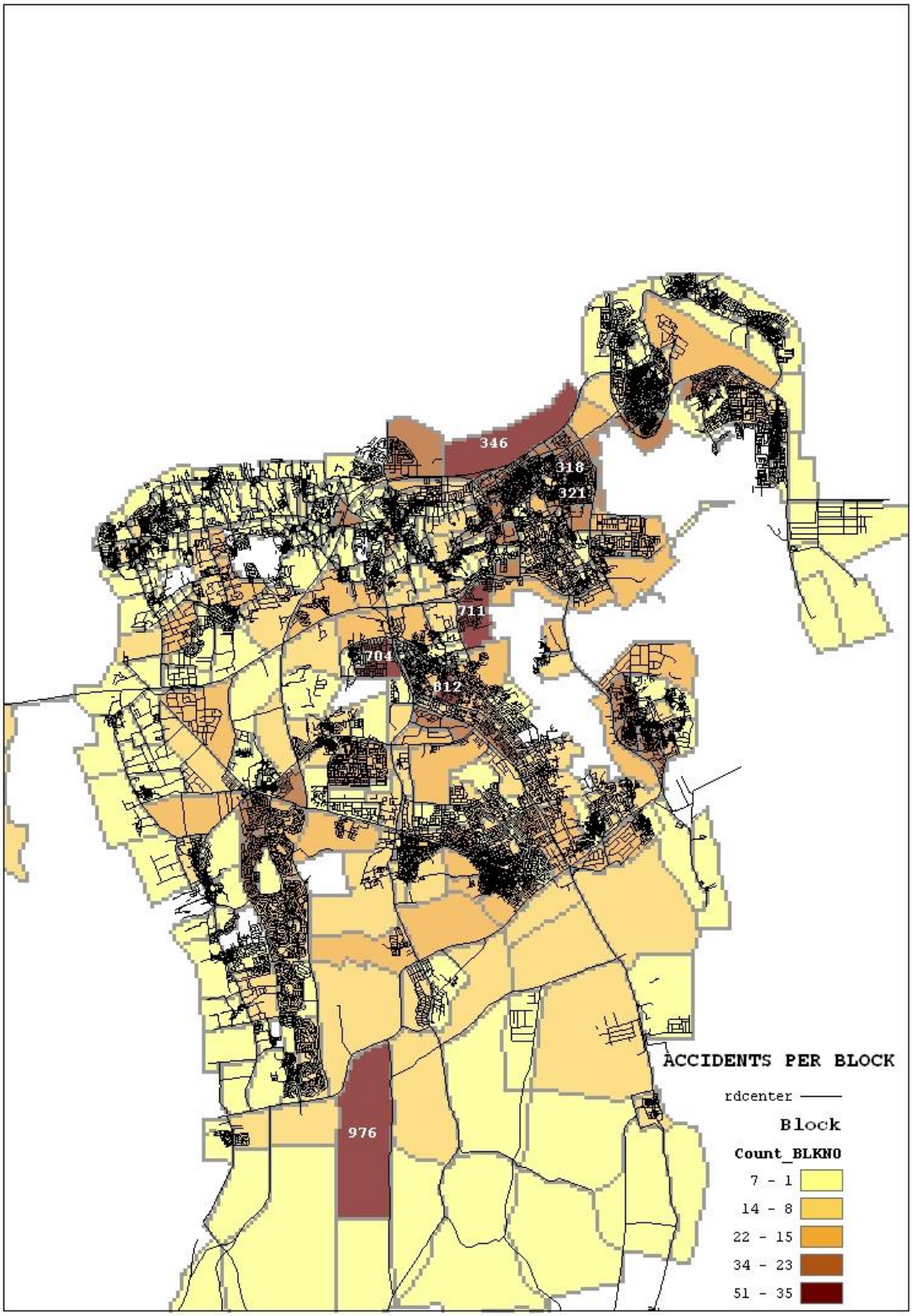

Fig. 8. Accidents per blocks.

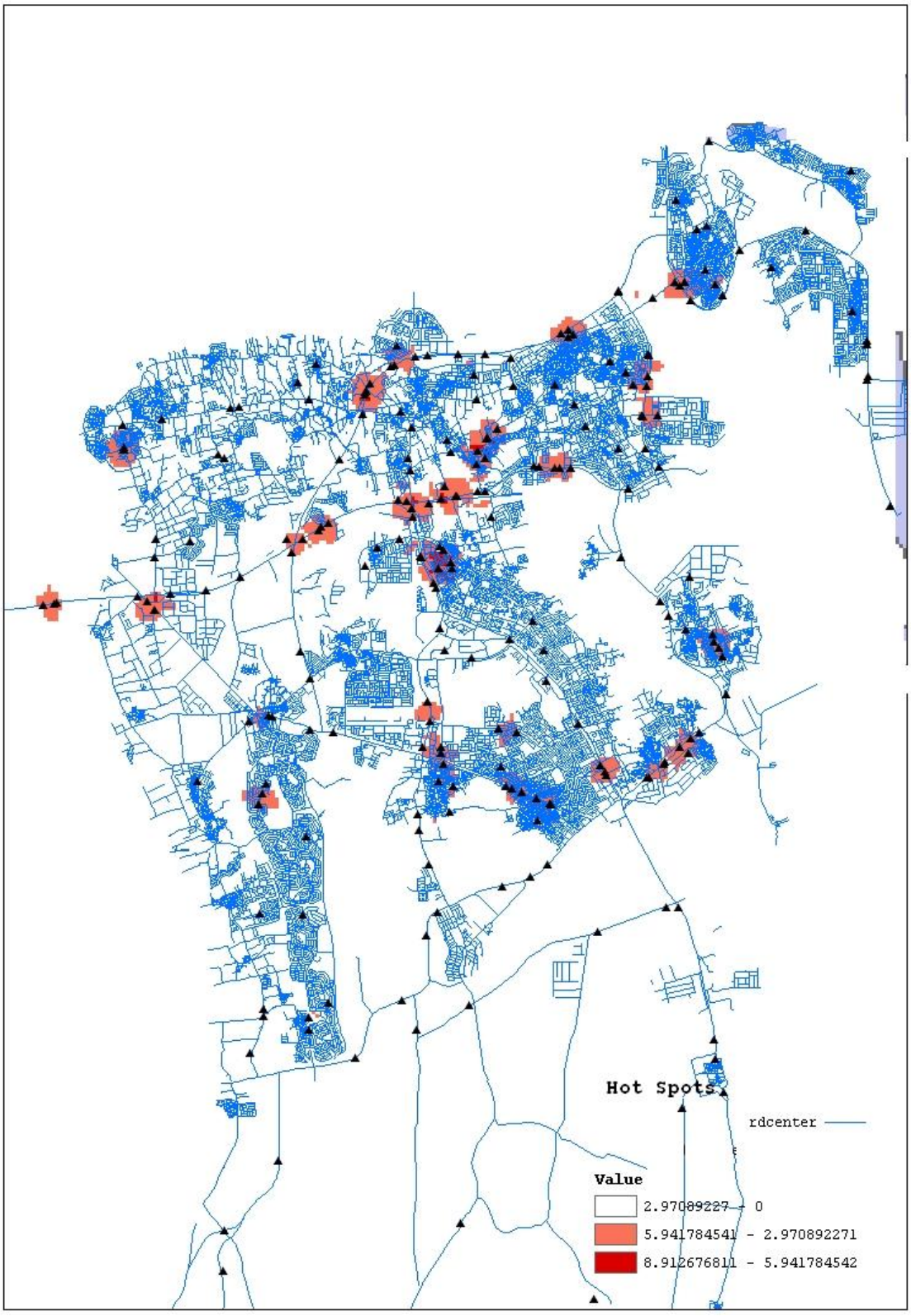

Fig. 9. Hotspots located in Bahrain.

Forgiving Design and Planning

High rate of injury related accidents are due to non-spatial related factors, as misconduct, life style, gender and culture, in which design and planning of roads have no direct influence. However, safety auditing plays an important role in enhancing traffic safety through proper design and planning of roadway networks. Some planning measures and physical alternatives are discussed next.

The urbanization pattern of Bahrain due to historical circumstances seems to be the major factor that dictated the accident pattern at the territorial scale. In fact, urban developments in Bahrain increased from 1,441 hectares in 1962 to 8,159 hectares in 1990 and to 11,543 hectares in 2007. Similarly, the industrial developments increased from 1,403 hectares in 1990 to 1,568 hectares in 2007. On the contrary, the agricultural area decreased from 6,887 hectares in 1990 to 4,042 hectares in 2007.

The economic prosperity in the Arab Gulf is another agent that leads to high annual growth rate in both the population of private cars and the vehicular traffic, entering Bahrain, through the causeway. This increase is reflected through the history of the daily traffic on the network (Table 2).

Despite the unavailability of reliable and clear data, deterioration in driving behavior of new generations also contributed to the increase in the accident rates along the major arteries.

The absence of public transport policy that introduces proper bus services and mass-transit modes such as metro, monorail, tram and sea ferry systems along, or close to, the major spine would be added to the previous planning factors that contribute in the reliance on private cars and the intensity of use of road networks.

The primacy of Manama, its conurbation with Muharraq and the urban sprawl along the northern coast made these cities the major recipients of accidents. In other words, the accidents in Bahrain are an urban related phenomenon. The shift of urbanization to the "barely populated" south, which serves mainly the military sectors, would therefore change the accident trend. The southern part of Bahrain is in the process of being heavily developed. New projects that have been undertaken recently in the south, such as Riffa Views, Al-Salam project, Al-Areen resort and wildlife camp, and Durrat Al-Bahrain islands would certainly alter this trend.

Accident distribution showed that the major arteries, both north to south and east to west, have the highest rate of accidents (Fig. 7). This is due to the geomorphologic character of Bahrain that is a long island in which these arteries constitute its spine that links south to north, and east to west, and ramifies many other settlements. As mentioned earlier, these highways lack proper safety barriers and high-tech facilities. Furthermore, the heavy reliance on private cars and the use of frequent at-grade intersections would be among the major factors in escalating the accident rates along these arteries. Road networks in Bahrain and in most of the Gulf Countries give far more attention to the vehicular traffic and drivers comfort compared to other road users that is often at the expense of people's safety.

It is quite interesting to mention that many roundabouts, due to congestion problems, are recently replaced by grade separated structures, as flyovers and underpasses. Many others have been replaced with signalized junctions. The latter might lead to lesser accidents the overall. Delays during the rush hours are also reduced. However, far greater injury severities due to red light crossings may occur (Al-Madani, 2009).

Due to the shortage of land and the urban sprawl effect, plots along the major arteries are under pressure of urbanization and development. This fact, most probably, is due to the pressure from the investors and the developers, who prefer the most accessible lands. This shows a lack of proper planning by the public authorities. A desperate consequence of this development is that both users' safety and traffic circulation, with regard to these arteries, will be compromised (Fig. 7). Existing highways will inevitably turn into simple large roads.

Many blocks in old Manama are characterized by their high rate of non-fatal accidents. It is evident that the concentration of services and public facilities in Manama are the reason behind these rates. For instance, the diplomatic area in Bahrain is mainly concentrated in two blocks of the capital and comprise most of ministries, hotels, embassies, entertainment sectors and banks. These are heavily used areas in Manama, thus generating huge amount of traffic and consequently accidents (Figs. 7 and 8). The reliance on private cars in the old city coupled with the morphology of its irregular and narrow streets would have also contributed in increasing non-fatal accidents frequencies.

A policy restricting car movements in the old city and the provision of shuttle transport mode, as mini-buses, would bring this rate down. Pedestrianization schemes, supported with proper facilities for the hot and humid climate, will surely reduce both congestions and accidents. It will also have positive effects on, among others, health and environment.

Table 2. Urbanization, population increase and motorization in Bahrain between 1980-2007

Parameter	1980/1981	1990/1991	2001	2007
Population:				
Manama	121986	136999	163696	281086
Muharaq	68964	82855	103576	159937
All Bahrain	350798	508037	650607	1039297
Number of Vehicles	69864	133552	229780	369124
Average Daily Traffic:				
Sh. Salman hwy.	19773	16856	33113**	19072*
Jabber Al-Ahmed hwy.	17532	21098	29083**	37733
Budaiya hwy.	18134	15236	24384**	27621
Sh. Isa Bin Salman hwy.	0	23722	35721**	51998
Housing Units:				
Manama	21050	27968	34210	-
Muharaq	10260	13834	17388	-
All Bahrain	52810	83470	105686	-

* Drop in ADT in 2007 is due to long term road construction work on grade separated structures.
** Data for the year 2003.

Paradoxically to the results of the present study, the block facing Bab Al-Bahrain, the old shopping city, found to have one of the highest accident rates. It has recently witnessed an unprecedented mega-projects, as Bahrain Financial Harbor (BFH) and Bahrain World Trade Center (WTC). These huge projects generate huge traffic within a small area. Such developments require special technical solutions to parking, pedestrians and traffic movement. These may include grade separated structures, well programmed traffic lights and taxing scheme.

Finally, on focusing on the schools in Manama, the accidents pattern, as shown in Fig. 10, illustrates that there is no evidence on a direct relationship between schools and accidents in the city. This result might, however, be misinterpreted as its gives the impression that the surroundings of schools are generally safe. In fact, the overall data on accidents shows that among the 6,616 recorded accidents, 1,371 victims are pedestrians, which represents more than 20% of the total number. This simply means that urban spaces in Bahrain cities are generally not safe.

The lack of evidence on the links between schools and accidents might also be explained by the way pupils approach to their schools that are mostly buses and parent's cars. A more detailed study combining the age of the victims, the time of accident, and the catchments areas of schools might highlight this issue.

Conclusions and Recommendations

The spatial analysis of traffic accidents in Bahrain showed that policies for reducing accidents should be tackled on many fronts. GIS can help in analyzing the data and taking both spatial and a-spatial measures. It can also be an efficient tool if utilized by the public authorities for the control of the traffic accidents trends at both short and long terms. The findings of this paper aim at guiding decision makers to some major considerations that are summarized next.

Non-spatial measures should target drivers that are mostly local males within the age group between 20-25 years as they were identified to be the most vulnerable ones to injuries. Lack of observance of proper driving attitudes, carelessness, lack of attention, over-speeding, high exposure rates and improper respect to pedestrians are among the major causes of accidents. One way to attain such dissuasion is through a system of points leading to suspension of driving licenses.

Traffic accidents in Bahrain are an urban phenomenon. The pattern of the accidents showed that they are mostly concentrated within the urban areas in the north, because of the concentration of services and public facilities in Manama, and along the major arteries. A distributive urban policy of the new spatial developments, some of which is already taking place, would therefore alter the accidents pattern. In fact, around half of the fatal accidents occurred along the arteries due to the territorial role of arteries, besides the high speed of cars and the differential speeds between them.

Facilities preventing frequent errant vehicles crossing the median to the other direction of traffic during accidents would also decrease accidents' severities on highways. Better barrier systems, proper canalization, reengineering of the road network for better control of speed, use of variable message system for incident control and use of high-tech enforcement tools would improve the traffic safety on the major highways.

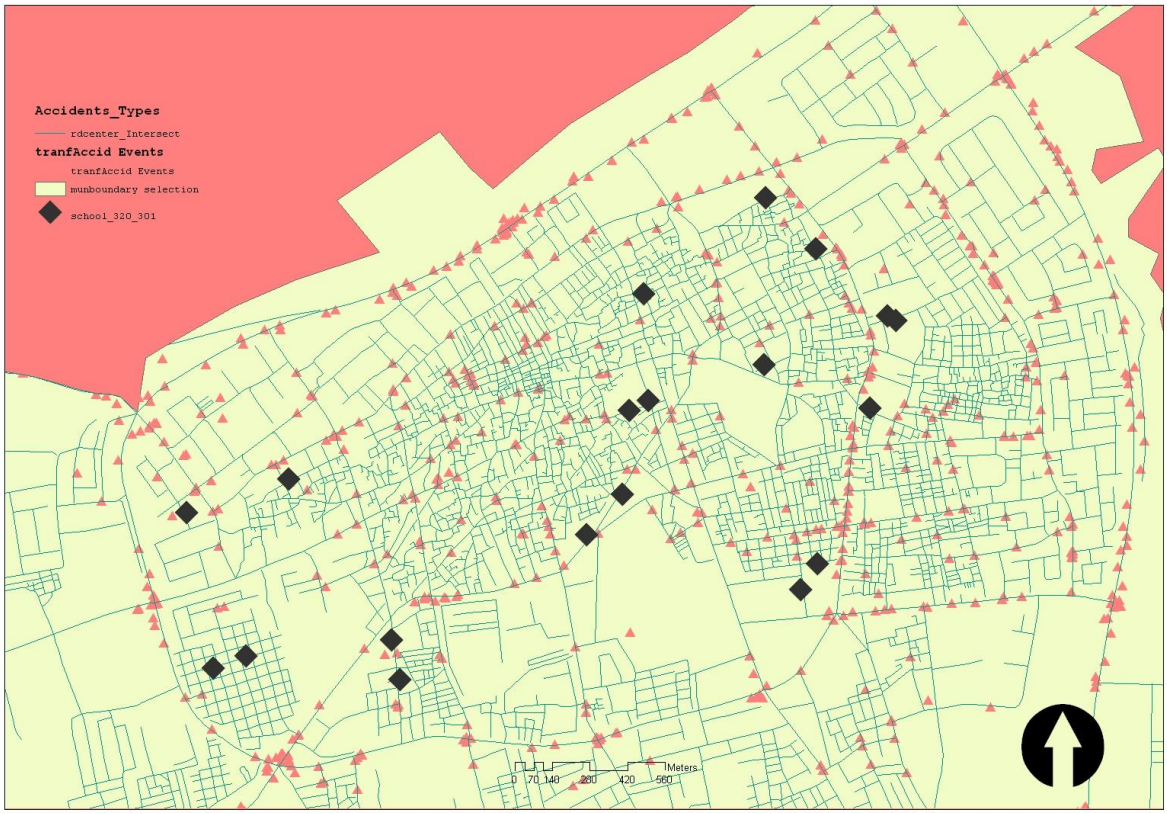

Fig. 10. Accidents pattern in Manama in relation to schools.

Hotspots and accidents clusters in the cities are concentrated in the densest populated blocks in the Kingdom, most of which are pedestrian related accidents. The mode of mobility within the cities is in favor of vehicular traffic and drivers comfort that is often at the expense of pedestrians. The presence of public transport, mass transit system and other mode of transport as sea ferry shuttles would reduce traffic volume and increase safety. GIS should be utilized to explore alternative urban planning through the zoning of urban activities, location and distribution of urban facilities.

At the urban space level, proper pedestrian crossing facilities and crossing prevention facilities would reduce the injury rates. Pedestrianization schemes with adequate facilities for hot and humid climate will surely reduce both the congestion and the accidents. This is specially necessary in most existing urban areas that comprises huge un-shaded areas.

Finally, in addition to engineering and planning solutions, policies devised to reduce the number of accidents should also encompass social awareness programs and devices to improve drivers conducts.

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الحوادث المرورية في البحرين
باستخدام التحليل الإحصائي ونظم المعلومات الجغرافية

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الكلمات المفتاحية: حوادث المرور، شبكة الطرق، التخطيط الحضري، البحرين، نظم المعلومات الجغرافية.

ملخص البحث. يوفر نظم المعلومات الجغرافية وسيلة ناجعة لتحليل حوادث المرور. فهو يربط الحوادث كعناصر مكانية بالتخطيط وتنظيم الفراغ الحضري وشبكة الطرق. وتهدف هذه الدراسة التي تقوم على بيانات عن الحوادث التي سجلت ما بين عامي ٢٠٠٠م و ٢٠٠٤م لدى شرطة المرور بالبحرين إلى تحليل نمط هذه الحوادث لغرض تحسين مستوى الأمن المروري في البلاد. وتقوم الدراسة على تقنيتين: الأولى هي استعمال نظام المعلومات الجغرافية لوضع الخرائط، والثانية إعمال التحليلات الإحصائية من جهة أخرى. وقد صنفت النتائج وفق عوامل الزمن والسائقين والأسباب، بينما قدمت تقنية المعلومات الجغرافية نمط توزيع الحوادث على الخريطة العمرانية استناداً إلى شبكة الطرق وتوزيع المستوطنات البشرية والمجمعات السكانية والنقاط الساخنة. ويتآزر جزءا الدراسة لإعطاء الصورة الكاملة حول الحوادث من حيث العوامل المؤثرة والأسباب المتعلقة بالتخطيط والتصميم والأسباب البشرية الأخرى. ويعتقد أن مثل هذه الدراسة سيكون لها الفوائد المتعددة للكثير من الهيئات الحكومية مثل وزارات الداخلية والصحة والبلديات وغيرها.