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Full Length Research Paper

Identifying Hazardous Road Locations in Saudi Arabia

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This paper aims to analyse road traffics accidents and identifying hazardous road locations in Saudi Arabia. Descriptive statistical analyses were used. Z score method based on accidents, injuries and deaths frequency per 100 km is suggested to determine the locations of the dangerous sites of road accidents, this method identified nine dangerous locations in the twelve counties all over Saudi Arabia. Also, the results show that the probability of death of at least five persons per day by car accidents is equal to one and the road accident deaths rate is 25.3 per 100,000 people, which is very high in compare with international levels, hence appropriate actions should be taken urgently to improve the safety of the traffic system in the country to prevent road traffic accidents from occurring and reducing the deaths and severity of injuries in the event of an accident.

Keywords: Traffic safety, Hazardous road location, Z score, Saudi Arabia

INTRODUCTION

The epidemic of road traffic accidents, deaths and injuries is worldwide public health problem (Ibrahim, 2002). It was estimated that 1.3 million people lose their lives each year as a result of road accidents and about 50 million are injured (WHO, 2002). Road traffic systems are seriously harming global public health and development. Repot of world health organization expected that without increased efforts and new initiatives, the total number of road traffic deaths worldwide and injuries is expected to rise by about 65% between 2000 and 2020 (Kopits and Cropper 2003; Murray and Lopez, 1966).

Traffic accidents and their consequences represent public health problem in Kingdom of Saudi Arabia (KSA); they are the leading cause of violent deaths, the fifth leading cause of death especially among males 16 to 36 years (WHO, 2006). More than 64500 people die and more than 36400 people are injured in over 153000 traffic accidents in KSA annually. Furthermore, the cost of traffic crashes to the country is estimated at $5.6 billion dollars a year (Bendak, 2011; Muhammad, 2009). As compared with most of the developed countries, KSA performs still below par concerning traffic safety. Therefore, the concerted efforts of the society, the governmental and private organizations, and academic institutions are necessary to improve road safety system and to reduce the number of fatalities and injuries. In this paper we determine the general trend of traffic accidents and identify dangerous roadways in KSA network. Next, the number of deaths due to accidents was modeled through Poisson distribution. Finally, the structure of the underlying road network was taken into account and the number of accident, injuries, and deaths were used for identifying hazardous locations all over the KSA. A step further was an investigations and analysis of road accidents and mortality in KSA at region level.

Hazardous Road Locations

Identifying hazardous road location is very important in a highway safety improvement project (Montella, 2010). It involves the key aspects of defining the site, setting the criteria of hazardous, using, for example: frequency, rate, rate quality control, or potential crash reduction method (loo, 2009). Elvik (2008) defined hazardous road location as any location that has a higher expected number of accidents than other similar locations as a result of local risk factors present at the location. Practically, these locations can be determined in terms of the recorded number of accidents. However, the definition of hazardous road locations may be determined on the basis of local circumstances that contributed to accidents. For example, accidents that occur due to adverse road design should have a greater influence in defining accident hazardous locations than those that result from impaired driving. Unfortunately, finding a pattern of contributing factors is usually not a simple task because of their complex interaction. For example, if the weather conditions are bad, driver may drive more cautiously. If the road is improved to be a standard highway, driver may derive faster with less caution than they were before the improvement of the highway.

In several literatures, the identification of hazard road location means the process of plotting accidents locations on the road network maps, these locations are referred to as black spots (http://www.trl.co.uk/). Thus, an accurate and complete data are very important for this process. If the complete record data about the locations is absent, it may be possible to start the process based only on local known knowledge of locations at which accidents occur most frequently. However, it is preferable to identify hazardous locations in an objective way using accidents records.

Hazardous road locations should be determined after doing a summary of all the worst locations. Then a cutoff can be made at the level of the 50 worst sites (http://humanservices.alberta.ca). In the United Kingdom, hazardous road locations may well have when only five injury accidents occurred in three years. In Austria, a hazardous road location is any location that satisfies one of the two criteria: (1) To have 1.3 or more similar injury accidents within 3 years and a risk coefficient $R_t \geq 0.8$, R_t is defined as

$$R_t = x/(0.5+7\times10^{-5}\times AADT)$$

where *AADT* is the annual average daily traffic and X is the number of injury accidents during three years. (2) To

have 5 or more accidents of similar type during one year (Islam, S., Mannering F. 2006).

A number of criteria should be considered when identifying a hazardous road location. Of these, it is necessary to define the site, route or area, and to use the same time period (usually, accidents per year) and same length of highway (e.g. per 100 kilometer), in china spatial scale of crash hot spot is suggested as 500 m (Becky, et al; Lu, et al 2003).

Accident frequency is the simplest identification criterion, in which location are ranked in descending order of observed accident frequencies and the total number of accidents is divided by segment length and time period. The result is the value showing accidents per year per kilometer. Other simplest method of identifying hazardous road locations based on the number of total accidents during a period of time and the accident rate (number of accidents divided by traffic exposure). Selection of location to be a hazardous road location depends on whether the number of accidents greater than a critical value or not, or accidents rate is greater than the critical value or not (http://www.trl.co.uk/). In addition to theses, there are a number of methods in the literatures that can be used for identifying hazardous road locations in term of the record number of the accidents. For example, equivalent property damage method, crash rate method, proportion method, and EP method (Montella, 2010). The average annual daily traffic has been the most commonly measure used in the literatures to reflect traffic conditions (Christoforou, 2001; Islam, 2006; Kim, et al., 2006; Mouskos, et al., 1999; Qin, et al., 2004).

METHODOLOGY

Data

Traffic data from 2003 to 2012 were analyzed for roadways in twelve KSA counties resulting in information about the number of accidents, injuries and deaths as a result of traffic accidents. Two sets of analysis were carried out on the database. First was a descriptive analysis of the data to determine the general frequency rates of accidents and the resultant deaths. A second identified hazardous road locations using the data of highway accidents along years 2010-2012 for the twelve counties. Previous research on crash hot-spot identifications (Cheng and Washington, 2005) suggests that an average of three years crash data should be used to detect high crash concentration locations. These counties are: Makkah, Medina, Riyadh, Eastern Regions, Northern border, Asir, Tabuk, Najran, Jazan, Hail, Al-Jawf and Al-Qassim (see Figure 3).

Statistical analysis

To estimate the likelihood of death by road accidents, we treat the number of deaths as a Poisson random variable; with the average of 17 people killed every day (this average is calculated from the traffic accident data of 2012). Assuming that the number of deaths due to accidents at any site varies randomly from year to year, the probability of death could be given by

$P(x) = (m^x e^{-m})/x!$, x =0, 1, 2,…

where x is the number of deaths due to accidents per day for which the average number of death is m. This equation is used to calculate the probability of death due to traffic highways accidents.

Z score statistics is proposed to identify hazardous road locations based on the number of accidents, deaths, and injuries. We calculate the number of accidents, deaths and injuries per 100 km (road section) on a highway between each two cities, and then Z-score statistics was calculated as follows:

$Z = (X-m)/s$

where X is the number of traffic accidents per sector, m is the average number of accidents and s is the standard deviation.

This equation used for calculating Z score for accident as well as deaths and injuries. Negative values of Z score were excluded. The positive values were ranked; and the large value was considered as an indicator of high risk of road. The analysis was carried out using the software package SPSS 11.0.

RESULTS

Descriptive analysis of accidents data

The analysis of traffic accidents data plays an important role as a tool for the evaluation of road traffic safety as

Table 1. The number of traffic road accidents, injuries, deaths and deaths per 100000 population in KSA (2003-2011)

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011
Accidents	261872	293281	296015	283648	435264	485931	484805	514492	544179
Injuries	30439	34811	34441	35884	36025	36489	36562	37904	39245
deaths	4293	5168	5982	5883	6358	6458	6142	6648	7153
Death per 100000	--	--	26.01	24.82	26.27	26.04	24.18	2453	25.10

Table 2. Paired t- test for inside city accidents and outside city

Accidents	Mean difference	t- value	p-value
Inside cities vs. Highways	-93.8	-2.53	0.01

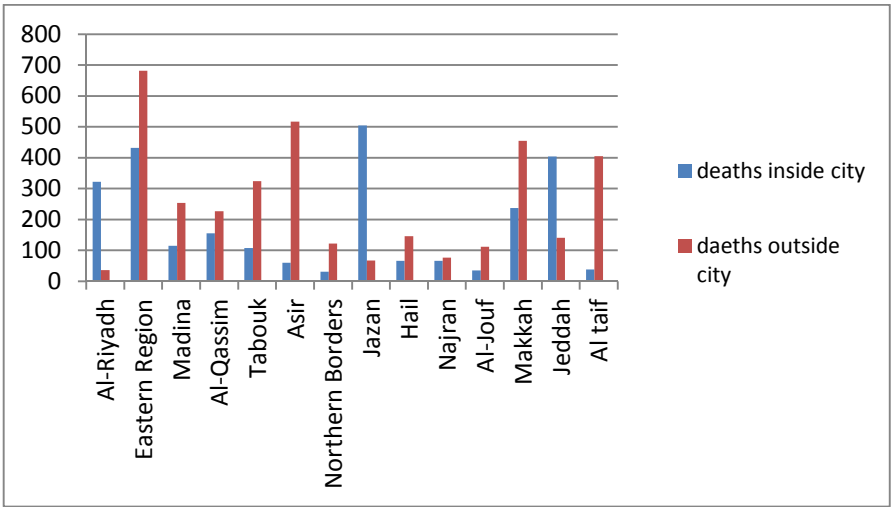

Figure 1. Accidents road deaths inside city compared with accidents road highways deaths.

well as guidance to improve the management of road networks to be safer. The data collected from the various traffic departments in KSA are the recorded number of accidents each year and the resultant deaths and injuries.

Table 1 show the evolution of traffic accidents, injuries and mortality expressed in term of deaths per 10,000 population since 2003. The general trend of them reported during the period 2003 to 2011 is steady increased. This is partly due to the increase in registerd vehciles as well as the construction and rehabilitation of paved roads over tha last 10 years that has led to increased speeds. Between 2005 and 2011, the number of accidents increased by 84%, the number of fatatlities

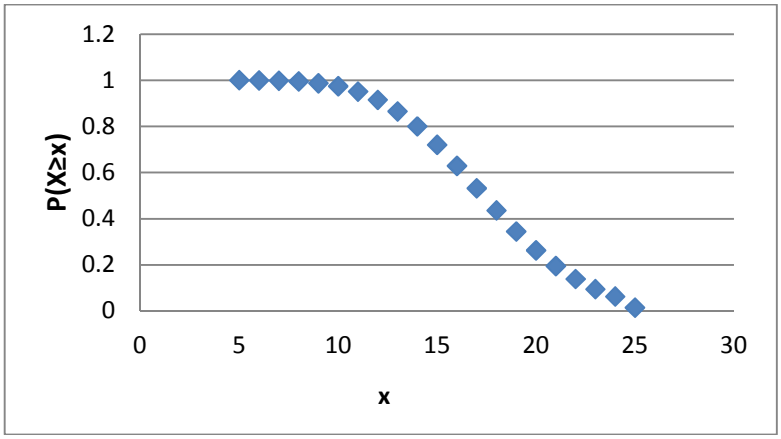

Figure 2. Probability of deaths due to accidents in KSA

Table 3. Distribution of deaths, injuries and accidents on highways by regions during the period 2010-2012

Region	Deaths	Injuries	Accidents	(Deaths/accident)%	(Injuries/accident)%
Riyadh	282	1419	1844	15.29	76.95
Makkah	415	1171	687	60.41	170.45
Madina	175	920	703	24.89	130.87
Qassim	50	635	759	6.59	83.66
Alshargia	245	1149	1179	20.78	97.46
Asir	33	93	80	41.25	116.25
Tabuk	77	618	714	10.78	86.55
Hail	55	520	564	9.75	92.20
Northern region	38	382	344	11.05	111.05
Jazan	32	97	92	34.78	105.43
Najran	35	311	466	7.51	66.74
Al-Jouf	13	102	222	5.86	45.95

increased by 19% and the number of injuries by 14%. While, in the same time period, the road trafic mortality rate, expressed in term of deaths per 100,000 decreased by 3.5% and the average death is about 5930 people annually. In the year 2011, the number of accidents is 544179, 5% increase compared to the previous year.

Based on the assumption of the normality of data, Table 2 represents the results of paired t test to see whether there is significant difference between the mean number of traffic accidents occurred outside cities and the mean number of traffic accidents occurred inside cities. The results show that accidents occurring outside

Table 4. Summary of Z score results based on accidents deaths per 100 km for the most hazardous road locations

No.	Road		Z- score
	From	To	
1	Shargyah	Riyadh	3.52
2	Al khafji	Alnaerya	3.03
3	Makkah	Medina	2.34
4	Alkharaj	Riyadh	1.52
5	Qassim	Medina	1.51
6	Jeddah	Makkah	1.47
7	Alnugrah	Qassim-Albatra	1.21
8	Riyadh	Makkah	0.97
9	Mastora	Makkah	0.91
10	Zanban	Makkah	0.78
11	Ta'if	Makkah	0.59
12	Riyadh	Dammam	0.39

cities are significantly more ($P < 0.05$). This is because of the vehicle speed is significantly increased on the highway and consequently, the deaths resulting in the highway accidents are more than that occur inside cities, especially, the vehicles may be loaded by more people.

Modeling of road accidents deaths

The results of calculating the probability of death as a result of accident is shown in Figure 2. It is clear that the probability of death of at least five persons per day in Saudi Arabia residents is certain ($P = 1$). This is a highest rate regionally and globally and it put road accidents in the top of epidemics that kill people in KSA. Also, it is clear that the probability of at least 25 persons die per day is 0.015, this number decrease until it reach 5 persons per day with the probability one.

Table 3 shows the rate of deaths and injuries as a result of accidents for each county in the years 2010-2012. The general rate is 25.3 per 100,000 people. It is clear that Makkah, the holy county, has the highest rate of death, where the number of deaths as a percentage of accidents is 60.41; meaning that in each 100 accidents the expected number of deaths is about 60 persons. This rate put Makkah highways as the most hazardous, followed by Asir (41.25), Jazan (34.74), Medina (24.89), and Riyadh (15.29). Al-Jouf has the lowest rate (5.86).

To show the relationship between injuries and accidents (Table 3), we calculate the rate of injuries as a percentage of accidents. The results reveal that Makkah (170.45), Medina (130.87), Asir (116.25), Northern region (111.05) and Jazan (105.43) are the counties with the highest rate of injuries, while Al-Jouf (45.95) is the county with the least rate. Alshargia, Hail, Tabuk, Qassim, Riyadh and Najran show a moderate rate ranging from 66.74 to 97.46.

Identification of Hazardous locations

The results of standard Z score as a measure to identify the high risk roads due to the deaths and injuries per 100 km is presented. Figure 3 presents the road network in KSA. The results, according to the deaths due to traffic accidents on highways, indicate that Shargyah-Riyadh highway, in Eastern region, is the most hazardous area. The mean number of deaths is above the overall average

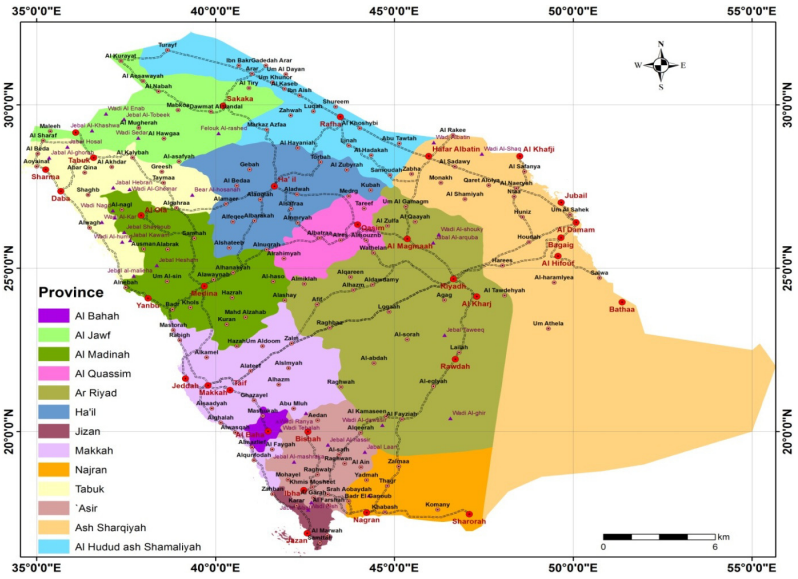

Figure 3. Road network in KSA

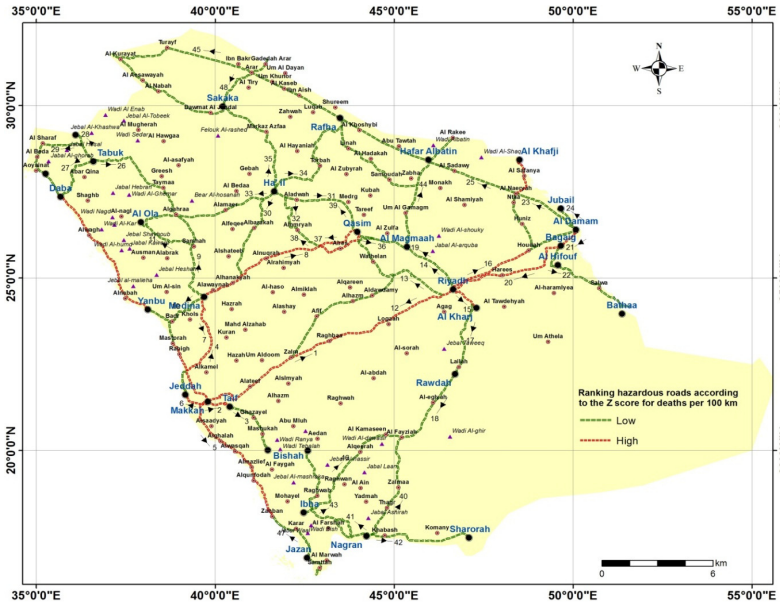

Figure 4. Map obtained by Z score index methods based on deaths per 100 km. Hazardous highways locations are represented by red color. Green color indicates roads with low accidents fatality.

Table 5. The most hazardous road locations based on Z score for injuries per 100 km

No.	Road		Z score
	From	to	
1	Qassim-Albatra	Alnugrah	3.81
2	Al khafji	Alnaerya	2.84
3	Makkah	Medina	2.55
4	Qassim	Medina	1.66
5	Riyadh	Alkharaj	1.44
6	Riyadh	Shargyah	1.35
7	Makkah	Ta'if	0.82
8	Jeddah	Makkah	0.80
9	Albatra	Alnmryah	0.50
10	Medina	Tabuk	0.83
11	Riyadh	Makkah	0.40
12	Riyadh	Qassim	0.24
13	Qassim	Almouzanb	0.24
14	Makkah	Mastorah	0.09
15	Hail highway	Medrg	0.09

Table 6. The most hazardous road locations based on Z score for accidents per 100 km

No.	Road		Z score
	From	to	
1	Qassim-Albatra	Alnugrah	3.52
2	Alnaerya	Al khafji	3.11
3	Riyadh	Alkharaj	2.45
4	Medina	Makkah	1.91
5	Medina	Qassim	1.41
6	Riyadh	Makkah	1.31
7	Riyadh	Shargyah	1.06
8	Makkah	Ta'if	0.86
9	Tabuk	Medina	0.55
10	Hail highway	Medrg	0.51
11	Makkah	Jeddah	0.48
12	Riyadh	Qassim	0.41
13	Najran	Abha	0.17
14	Salwa	Alhafouf	0.11
15	Tabuk	Dauba	0.05

Table 7. The most hazardous road locations based on them mean ranks of Z-score values for the three characteristics (deaths, injuries and accidents)

No.	Road	rank
1	Alnaeryah -Alkhafji	1
2	Qassim-Albatraa -Alnugrah	2
3	Medina -Makkah	3
4	Riyadh -Alkharaj	4
5	Medina -Qassim	5
6	Riyadh -Sharqiyah,	5
7	Makkah -Jeddah	6
8	Makkah -Riyadh	7
9	Makkah -Ta'if.	8

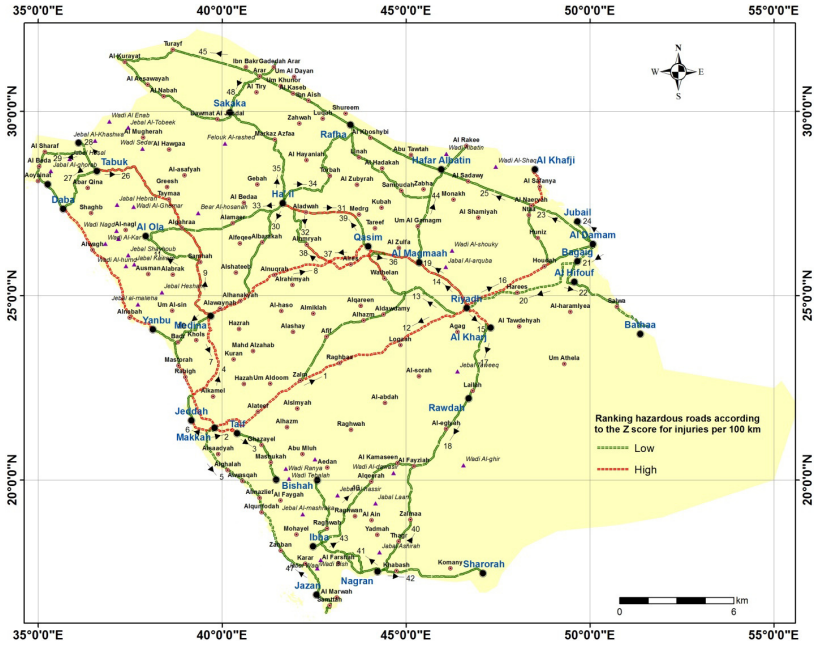

Figure 5. Map obtained by Z score index methods based on injuries per 100 km. Hazardous highways locations are represented by red color. Green color indicate road with low accidents injury.

by 3.52 standard deviations, see Table 4. It followed by Alnaeryah –Al Khafji highway, Madina–Makkah highway, Riyadh-Al-kharj and Riyadh-Dammam for which deaths average is above the overall death average. The map in Figure 4 illustrates the hazardous areas based on the standard Z score of deaths.

Table 5 presents the results of standard Z score based on the number of injuries due to highways traffic

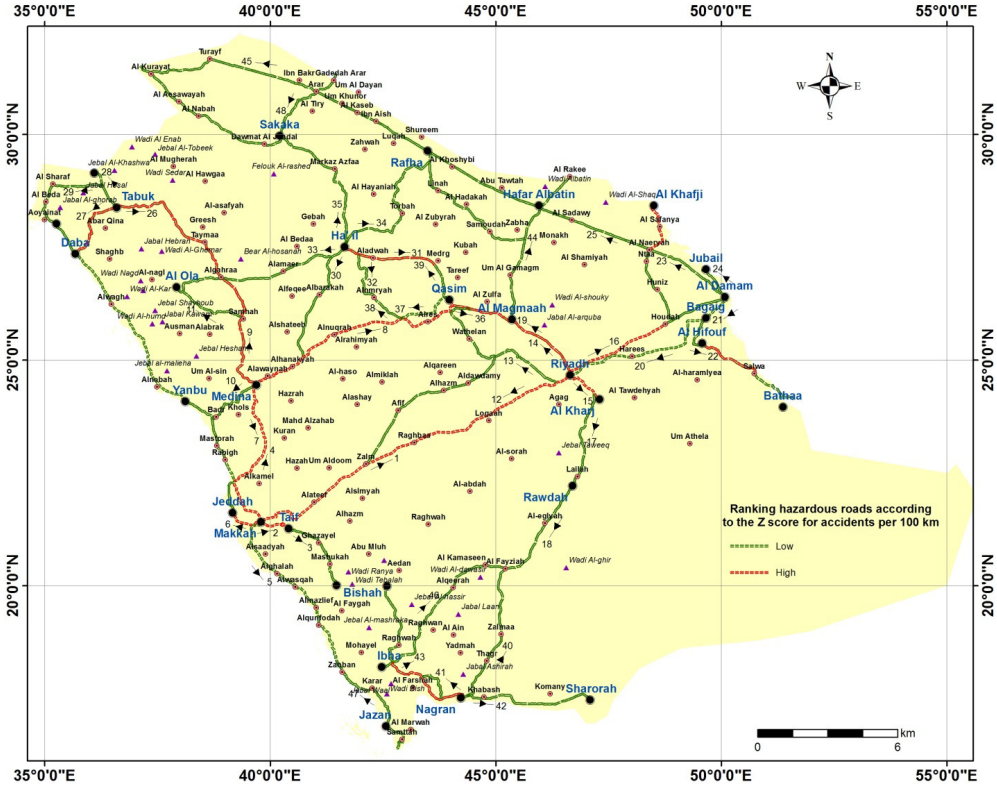

Figure 6. Map obtained by Z score index methods based on accidents per 100 km. Hazardous highways locations are represented by red color. Green color indicate road with low accidents.

accidents per 100 km. From the result presented on the map in Figure 5, it is quite clear that the most hazardous locations are four main highways in the country, i.e. Qassim- Albatraa -Alnugrah with Z score equal to 3.81, followed by the highway of Alnugrah–Al Khafji, Madina-Makkah and Madina-Qassim. The less hazardous location is the highway of Hail-Medrg.

Table 6 presents the results of standard Z score based on the number of traffic accidents. The results indicate that the most hazardous accidents is the area of Qassim-Albatraa-Alnugrah highway with Z score value of 3.52 followed by Alnaeryah-Alkhafji highway with Z score value of 3.11 followed by Riyadh-Al-kharj with standard score 2.45. The less dangerous area in terms of accidents is Tabuk-Dhuba. The result is presented on the map in Figure 6.

Based on the three variables, the number of deaths, injuries and accidents, Z score values, in Table 7, indicate that the most hazardous highways are: Alnaeryah -Alkhafji, Qassim-Albatraa -Alnugrah, Medina -Makkah, Riyadh -Alkharaj, Medina -Qassim, Riyadh -Sharqiyah, Makkah – Jeddah, Makkah - Riyadh and Makkah -Ta'if. These roads can be summaries in the following highways: 1) Alnaeryah -Alkhafji 2) Jeddah – Makkah-Ta'if – Riyadh –Shargyah 3) Riyadh Alkharaj 4) Makkah-Medina (see Figure 3).

DISCUSSION

In this study, we identified hazardous locations of highway accidents by frequency of deaths and injuries related to accident sites. Accidents occurring in all regions of KSA were investigated. Z score index was calculated for each 100 km in each highway all over the country, and then we rank the highway according to their z score value. High Z score value indicates high risk location and zero Z score value indicates no risk, as well as negative Z score value. The index takes into account not only the number of accidents, but also the number of deaths and injuries and combined this information by using the means of ranks in order to arrange the hazardous locations. This suggested index in the present research is based on a three year available data of highway accidents: deaths per 100 km, injuries per 100 km and accidents per 100 km. It is simple, applicable and straightforward method of identifying hazardous road locations. We identified the hazardous location in the followings (Figures 4, 5, 6):

1. Highway: Riyadh -Sharqiyah
2. Highway: Riyadh – Ta'if – Makkah -Jeddah
3. Highway: Qassim- Medina -Makkah

Once these highways are investigated closely, it is identified that in all these highways connect the capital Riyadh and the Holy cities (Makkah and Medina) with the biggest cities in KSA, which justify our strong evidence that theses location are being of high crash locations in the country; therefore a safety review is necessary in these locations.

We have investigated traffic accidents data set for the last nine years and we found some interesting results. Of these, the numbers of accidents, injuries and death are increasing over time in KSA. One can say that rising per capita income in KSA has contributed to the increase in the number of vehicles (an estimated 10- 11 million vehicles across the KSA (https://www.cia.gov/libraray, 2011), and this will contribute in the epidemic of road traffic accident, deaths and injuries in KSA. The probability of death for at least five persons per day by car accidents in KSA residents is found to be certain with probability one. One can say that the most important factor in estimating this likelihood of death of car accident is the number of kilometers driven or ridden. If a person does not commute, or does not own a car, the probability is much smaller than that of a traveling salesman. This reflects the size of the problem of traffic accidents and the size of the human and economic resources lost that are enormous in KSA. Also, the result showed that, the road accident deaths rate is 25.3 per 100,000 people, which is very high in compare with international levels. According to International Road Traffic and Accident Database, the fatality rates per 100,000 people were 9.3 in Australia, 9.5 in Germany and 15.3 in the USA (Wong, et al,. 2002).

The results suggested that the total numbers of deaths due to accidents inside cities is smaller than the numbers of deaths on highways in all regions except Riyadh, Jeddah and Jazan; accidents occurring outside cities are significantly more severe than accidents occurred inside cities because vehicles outside cities are averagely loaded with more people and the vehicle speed is significantly increased.

Traffic accidents and their consequences are clearly a public health problem in KSA; they are the leading cause of violent deaths, the fifth leading cause of death and the leading cause of death in males 16 to 36 years (Muhammad H. 2009). Furthermore, the cost of traffic crashes to the country is estimated at $5.6 billion dollars a year, (WHO, 2006).

In order to combat road safety problem in KSA, there needs to be close coordination and collaboration, using a holistic and integrated approach, across many sectors and many disciplines in KSA. Recently the authority activated an automatic traffic control and management system called “Saher” to improve the level of traffic safety in some of the major cities. The system is a network of digital cameras linked to the National Information Center of the Ministry of Interior to monitor traffic accidents and violations. In particular, high speed and violation of traffic sign which the main causes of traffic accidents. Unfortunately, “Saher” does not appear to effectively reduce traffic accidents. Making a road traffic system less hazardous requires recognition that the human body is highly vulnerable to injury and that humans make mistakes. Thus, appropriate actions should be taken urgently to improve the safety of the traffic system for all its users which leads to the safe and sustainable road , and will end by reduction of exposure to risk; preventing road traffic accidents from occurring, reducing the deaths and severity of injuries in the event of an accident

CONCLUSIONS

The ability to identify hazardous locations of road accidents is necessary in planning to solve the traffic safety problems. It helps to better design educational and awareness programs targeting the group associated with a particular safety problem. This need an investigation of the factors contributing to accidents and causes related to them. However, this paper does not examine in depth these factors because of the lack of the needed data. Thus, we recommend that the traffic security administrations should properly identify the cause of accident in the accidents reports that they use. Also, the data should be available to researchers all over the country. And this might consider a launching point for further researches in this area.

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