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RESEARCH ARTICLE

Risk assessment of water resources pollution from transporting of oil hazardous materials (Sanandaj-Marivan road, Kurdistan Province, Iran)

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Abstract
Water pollution is one of the most important environmental challenges and also one of the main causes of death in the world. Transporting oil products on roads by trucks and their accidents lead to the release of these chemicals into the environment, resulting in water resources pollution. Thus, the main goal of this study is to evaluate the risk assessment of the water resources pollution in the road of Sanandaj to Marivan, Kurdistan province, Iran. Six scenarios for four types of hazardous materials in two seasons of the years were considered. The road was then segmented, and the probability of accidents in each segment was calculated by the Poisson regression method. Two scenarios were selected for analysis since truck accidents had happened mainly in spring (scenario 1) and winter (scenario 4). According to the results, the total risk of water contamination path is 20%very low, 19% low, 29% moderate, 28% high, and 4% very high. Also, according to scenario 1, 14% of the total area of the study area is very low risk, 23% low risk, 15% medium risk, 6% high risk, and 42% are very high risk. Based on scenario 4, 39% of the total area of the study area has a very low risk, 44% low risk, 13% medium risk, 4% high risk. This simply means that this road is not very suitable for transporting hazardous oil products.

Keywords HazMat · Truck accident · Risk assessment · Water resources pollution · Poisson regression · Sanandaj-Marivan road · Responsible

Introduction

One of the most critical global environmental challenges is the pollution of surface water and groundwater, which is due mainly to human activities. These activities include a large variety of actions, each of which can potentially be harmful to the environmental elements. They have increasingly been intensified during the past three decades, threatening most natural resources, including water, soil, and air all over the world. One of these anthropogenic activities is the transportation of hazardous materials (HazMat) that are inherently very dangerous.

Nowadays, in most countries of the world, particularly in industrialized countries, the transport of HazMat shows an increasing trend, and road accidents have become one of the most deleterious challenges of transportation today (Paltrinieri et al. 2009). Truck accidents that occur during transporting HazMat always have the risk of becoming a disaster for the environment and society. According to the US Department of Transportation, a hazardous material is any item or agent (biological, chemical, radiological, and/or physical), which has the potential to cause harm to humans, animals, or the environment, either by itself or through interaction with other factors (DOT 2004). The European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) classifies HazMat into nine categories as follows (Torretta et al. 2017):

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- Explosive substances and articles
- Gases, including compressed, liquefied, and dissolved under pressure gases and vapors
- Flammable liquids
- Flammable solids, self-reactive substances, and solid desensitized explosives, substances liable to spontaneous combustion, substances which, in contact with water, emit flammable gases
- Oxidizing substances, organic peroxides
- Toxic substances, infectious substances
- Radioactive material
- Corrosive substances
- Miscellaneous dangerous substances and articles

Transporting oil products throughout the roads created many accidental releases of these materials into the environment (Ambituuni et al. 2015). Transport of HazMat is classified as a low probability and high-intensity event (Bianco et al. 2009; Chakrabarti and Parikh 2011; Lozano et al. 2011) because the release of these materials into the environment can be harmful to the environment and humans. Therefore, despite the low occurrence of these incidents, their consequences will be very severe and sometimes catastrophic (Kara et al. 2003).

Truck accidents during transportation of HazMat lead to the releasing of these materials into rivers and dams, which causes source water pollution. Therefore, risk assessment of water resources pollution by the transport of hazardous substances on roads is high of necessity. The road Sanandaj-Marivan located in the Kurdistan Province, Iran, is one the main roads in Western Iran, transporting a huge body of third class of the hazardous substances including flammable liquids such as kerosene, mazut, diesel fuel, gasoline, argon gas, liquid gas, naphtha based on the ADR classification. This road has experienced many truck accidents during the past 20 years resulting in pollution of surface and ground waters along the route. Thus, the environmental risk assessment of this issue has attracted the attention of many researchers (Ambituuni et al. 2015).

In recent years, in many studies (Ardjmand et al. 2016; Conca et al. 2016; Huang et al. 2018; Saat et al. 2014; Torretta et al. 2017; Tubis 2018; Yang et al. 2010; Zhang et al. 2000; Zhao et al. 2012), the risk assessment of transporting HazMat has been evaluated with different approaches that most of them are based on routing approaches. Cordeiro et al. have studied an environmental risk model for accidents involving the transport of HazMat based on fixed and time-varying data and the implementation of methodological aspects of a geographic information system (GIS) (Cordeiro et al. 2016). Siqueira has developed a multiple-criteria analog model for assessing the vulnerability of rural basins to the release of HazMat into the environmentally protected area of Uberaba River, Brazil (Siqueira et al. 2017). The identification of transport risks was examined based on a combined assessment of road accidents and vulnerability to the release of hazardous substances. Machado et al. have introduced various scenarios of road accidents (Machado et al. 2018). Multiple-criteria analysis and GIS have also been used to assess the vulnerability of the environment to HazMat released from truck accidents. Wang et al. have used a risk assessment model based on the Bayesian network for the south-north water transportation project in China to predict the risk of transportation accidents (Wang et al. 2016). Rebelo et al. have applied a risk assessment model to water resources by focusing on the release of hazardous substances based on the general European Railway Agency (ERA) methodology (Rebelo et al. 2014). Machado et al. used a model of environmental vulnerability to hazardous material release in the highways based on a multiple-criteria analysis model (Machado et al. 2018). A risk assessment framework and decision-making tool based on GIS for chemical leakage was evaluated by investigating a case study in the situation of the nitrobenzene scenario in the Songhua river basin by Jiang and his colleagues (Jiang et al. 2012). AlRukaibi et al. developed an optimal risk-based route algorithm for transporting HazMat in Kuwait with an incident simulation scenario by ALOHA (a software for modeling propagation) (AlRukaibi et al. 2018).

The risk assessment of groundwater pollution based on the DRASTIC method was evaluated based on which a hazard zonation map was developed (Wang et al. 2012). The same approach was applied to assess the vulnerability of the inherent aquifer of groundwater to pollution in the Kathmandu valley, Nepal (Shrestha et al. 2016). Another research study (Bagherzadeh et al. 2018) evaluated the vulnerability of the Shimber Karsty site using the COP method. The study of groundwater vulnerability was carried out based on the GIS approach using the SINTACS experimental model, in the Zeuss-Koutine aquifer, southeast of Tunisia (Jarray et al. 2017).

Although many studies have been carried out on the transportation of HazMat and its risks to source water pollution, little is known about the risk assessment of water pollution stemming from the transporting HazMat on the road Sanandaj-Marivan. Transportation of these HazMat by trucks and truck accidents is frequently occurring in this road. This issue is a huge potential for pollution of water resources of the region. This study is among the first studies that have focused on the evaluation of the risk assessment of water resources pollution by the release of HazMat on the Sanandaj-Marivan road using a combination of affecting factors including geometric characteristics of the road, basin characteristics, season of the year, and truck accident data. This combination has received little attention in previous literature.

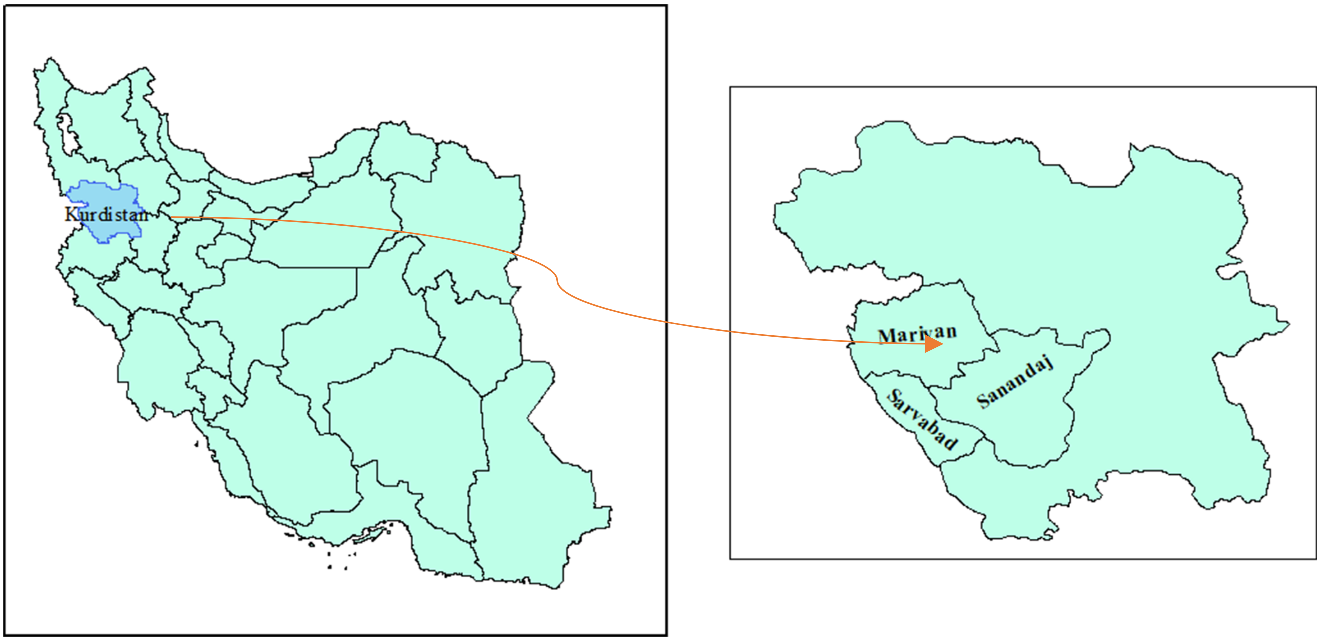


Fig. 1 Location of the route and the study area

Methodology

Study area

The study route is the Sanandaj-Marivan-Bashmagh transit road in Kurdistan Province, Iran. It is 150 km long from Faizabad Square in Sanandaj to Marivan city and to Bashmagh zero point of the border. This route passes from three towns, including Sanandaj, Sarvabad, and Marivan. There are many waterways along the road that are very close to the road, and in some parts, the distance between the waterway and the road is about 50 m. The Zrebar lake in Marivan, which is one of the most beautiful tourist attractions of the area, is very close to this transit road. The location of Kurdistan Province and towns are shown in Fig. 1. The entire road is shown by Google Earth in Fig. 2.

Data acquisition

Data on truck accidents during 2015 and 2016 were collected from the Traffic Police Office for assessment purposes of this study. The number of accidents by different seasons during the study period is shown in Fig. 3. Of 27 accidents, nine accidents occurred in winter, 8 in fall, 8 in spring, and 2 in summer, indicating the effect of season of the year on the number of accidents. The type and the number of released substances in accidents are shown in Fig. 4. The number of

Fig. 2 Sanandaj-Marivan road on Google Earth

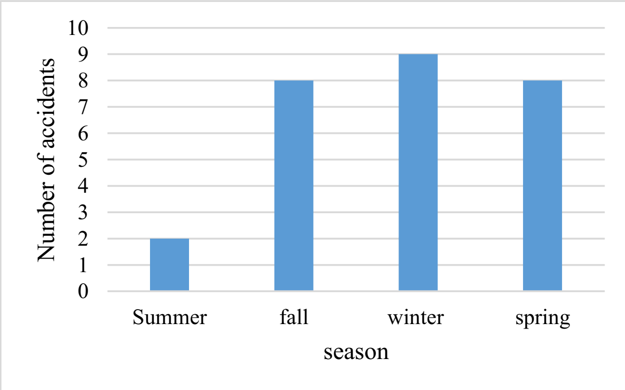


Fig. 3 Type of leakage and its frequency in truck accidents

accidents, the causes of accidents, and the percentage of them are shown in Table 1 and Fig. 5. It shows that the cause of 33% of the accidents is due to speeding over the speed limit.

Procedures of the research

In this study, a risk assessment formula and decision matrix are used to evaluate the risk assessment of water resources pollution from transporting HazMat throughout the road. The risk is equal to the probability of accidents multiplied by its consequences. Therefore, this study is consisting of two parts, including quantifying probability and quantifying the consequences of the accidents that their product is equal to the risk. An example of the reversal of oil trucks along the study road is shown in Fig. 6. Since the road is very close to waterways, the HazMat released from these accidents will reach the waterways is a very short time and cause irreparable pollution and damage.

The factors affecting truck accidents were first identified to calculate the probability of accidents. Poisson regression was then used to establish a relationship between the factors and the probability of an accident. After identifying the factors that affect the consequences of accidents, the levels of information

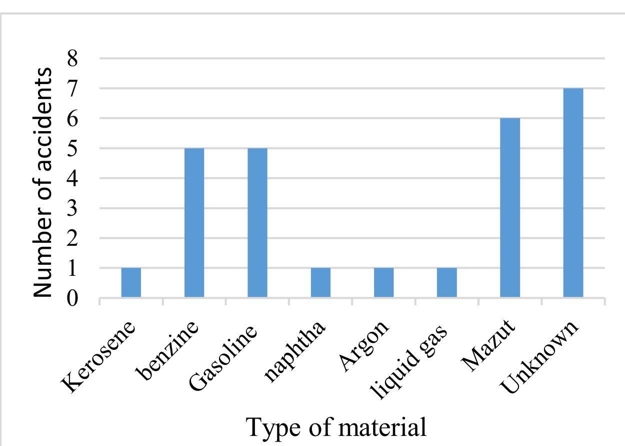


Fig. 4 Number of accidents in different seasons

for each factor were implemented in GIS to quantifying the consequences of accidents. Then, the analytical hierarchy process (AHP) was used, and weight was allocated to each index and sub-index. Finally, after the integration of information layers based on the weights of the factors, a raster map was created in which the weight of a pixel shows the consequences of accidents at that pixel such that the greater number has more consequences. Thus, the by-product of the probability of an accident and its consequences on the environment and water resources was considered as the risk of water pollution as follow (Li et al. 2007):

$$R = P \times C \tag{1}$$

Where R is the risk, P is the probability of an accident, and C is the consequence of the accident.

Calculations of the probability of accident occurrence

The number of data is usually approximated by Poisson distribution. In the Poisson regression model, the probable number of crashes follows a particular Poisson distribution. The Poisson model is used because of the discrete, non-negative, and sometimes rare occurrence of accidents (Li et al. 2007).

The prediction of road accidents is mainly performed using statistical models that provide a link between the likelihood of future accidents with past accident statistics and geometric characteristics of the road, such as horizontal curvature, line width, and road shoulder width. The Sanandaj-Marivan road was divided into 15 segments that each segment is 10 km in length to calculate the probability of accidents on this road. The probability of accidents in each segment was separately calculated.

Different models have been used in past studies to calculate the probability of accidents such as the Bayesian model based on GIS (Li et al. 2007), negative binomial model (Aguero-Valverde and Jovanis 2006; Chang 2005), generalized linear model (Dinu and Veeraragavan 2011), Poisson regression (Ma et al. 2008), and logistic regression and wavelet transform (Agarwal et al. 2016). Kinds of literature show that Poisson regression is the most widely used method; therefore, it is used

Table 1 The cause and percentage of accidents reviewed

Cause of the accident	Number of incidents	Percent
High speed	8	33.33
Human mistake	3	12.48
Turn left	2	8.33
Technical problem	2	8.33
Unsafe conditions	2	8.33
Distracting from the road	1	4.16
Unknown	6	25

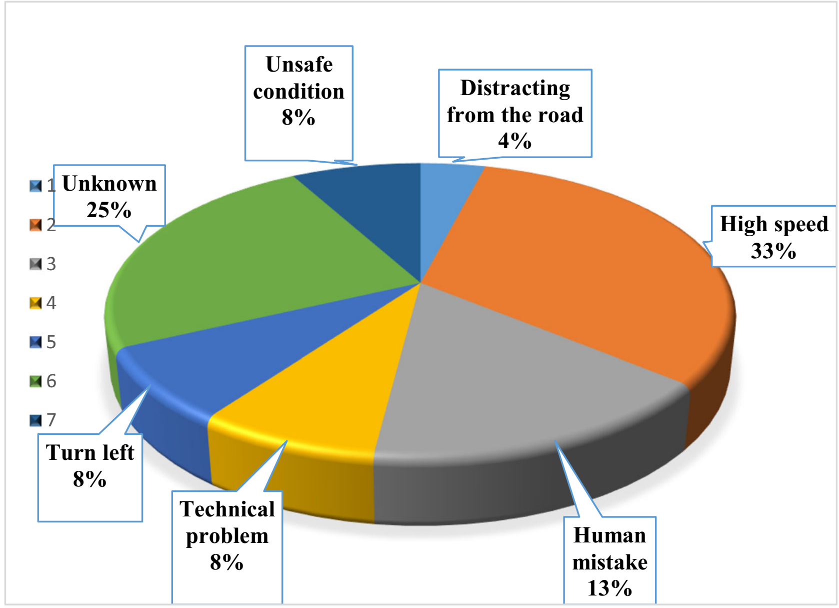


Fig. 5 The cause and percentage of accidents reviewed

in this study because of its accuracy and proper modeling of accidents. The effective factors on the probability of an accident are the mean slope of the segments, the width of the road, and the number of arcs in each segment.

In the Poisson regression model, the number of accidents in each segment is calculated as follow:

$$\log(\mu_i) = -4.586 + 0.166x_1 + 0.142x_2 + 0.305x_3 - 0.011x_3^2 - 0.010x_1x_2 + 0.011x_1x_3 \quad (2)$$

Where x_1 is the mean width of the segment, x_2 is the number of arcs in the segment, x_3 is the mean of the segment slope, and μ_i is the predicted mean of the number of accidents in the i^{th} segment in a year. By substituting the geometric characteristics of the road segments and the statistics of their past accidents in the Poisson regression model, the probability of an accident in each segment in a year is obtained.

Consequences of the accidents

After calculating the probability of accidents in each segment, the consequences of the accidents in each segment should be quantified. In this regard, the area of the roadside should be determined, which is impacted by the leakage of HazMat, and the consequences of this area should be investigated. The criterion for determining the width of this area was determined based on the maximum distance of the impact of HazMat, which according to previous investigations (Agarwal et al.

Fig. 6 An example of the reversal of truck containing chemical HazMat along Sanandaj-Marivan road

Table 2 HazMat and their impact area

Impact area	Example	Hazardous substance
In all directions 0.8 km	Gasoline, bitumen, oil, kerosene	Flammable liquids
In all directions 0.8 km	Plastics and asphalt	Flammable solids
In all directions 0.8 km	Herbicides and pesticides	Toxic and infectious substances

2016) and the type of dangerous materials transported on the road (Table 2), a strip with a total width of 1600 m (800 m from both sides of the road) was considered.

Then, the effective factors in the calculation of the consequences of HazMat leakage due to accidents were determined, which are shown in Fig. 7. These factors include two groups of geographical factors and the type, amount, and time of leakage factors. The first group of factors includes the rate of leakage of HazMat in the environment and the vulnerability of water resources to these leakages. The most important factors of the first group affecting the consequences of hazardous material leakage are the slope of the segment, the number of arcs in the road, drainage density, and proximity to surface waterways and groundwater. A digital elevation model (DEM) was generated to extract these geometric data. Each of these factors was implemented in GIS as a main layer of information, and also each of the main layers was divided into sub-layers. These layers and sub-layers were then weighted with AHP and were determined based on their significance and impact, and the weights of each layer and sub-layer.

The generated maps were then combined according to the weight determined in GIS based on the overlapping model

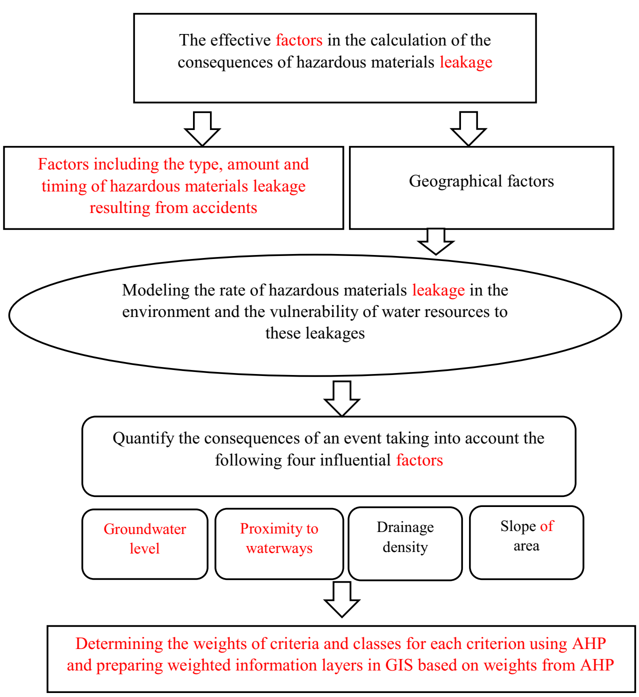


Fig. 7 Determining the effective factors in the calculation of the consequences of leakage of HazMat

index for each piece according to Eq. (2). The final output included the combination of all segments, and the final map is a combination of all layers for the entire road.

$$L = \frac{w_1 L_1 + w_2 L_2 + \ldots + w_n L_n}{w_1 + w_2 + \ldots + w_n} \quad (3)$$

Where L_i is the i^{th} layer, w_i is the weight of i^{th} layer, and L is the output layer, which is the combination of layers. The final output layer to the entire road is shown in Fig. 8.

Three scenarios (scenarios 1 to 3) with the highest importance (the highest weights obtained from the comparisons) were selected. In this stage, the statistics of the transported materials along the road and the released material due to accidents were not used in the calculations. Also, three scenarios (scenarios 4 to 6) with the highest occurrence in the past regarding the available statistical data were selected. These six scenarios and their weights after normalization are shown in Table 3. Scenarios 1 and 4 are selected as typical scenarios for demonstration.

The final consequence is obtained by taking into account the first and second order of criteria simultaneously in which the first-order criterion is a raster map, and the second-order criterion is a number which shows the weight of each scenario. The weight of each scenario in the final map is multiplied by combining the layers of information related to the first-order criterion, and the final consequence map for each pixel in the study area for each scenario is obtained.

$$C_j = L.S_j \quad (4)$$

where C_j, L, and S_j are consequence map of jth layer, the weight of each scenario, and jth raster map, respectively. The consequence map related to scenarios 1 and 4 is shown in Figs. 9 and 10.

Results and discussion

Geometric characteristics of the road such as the mean slope of the segment, mean of the road width, and the number of the arcs of each segment was collected in order to calculate the probability of accidents in 15 segments by the Poisson regression method. Then, the average number of accidents of the trucks that transport HazMat was estimated in a year. By normalizing this number, the probability of accident occurrence of the trucks transporting HazMat was calculated in a year in

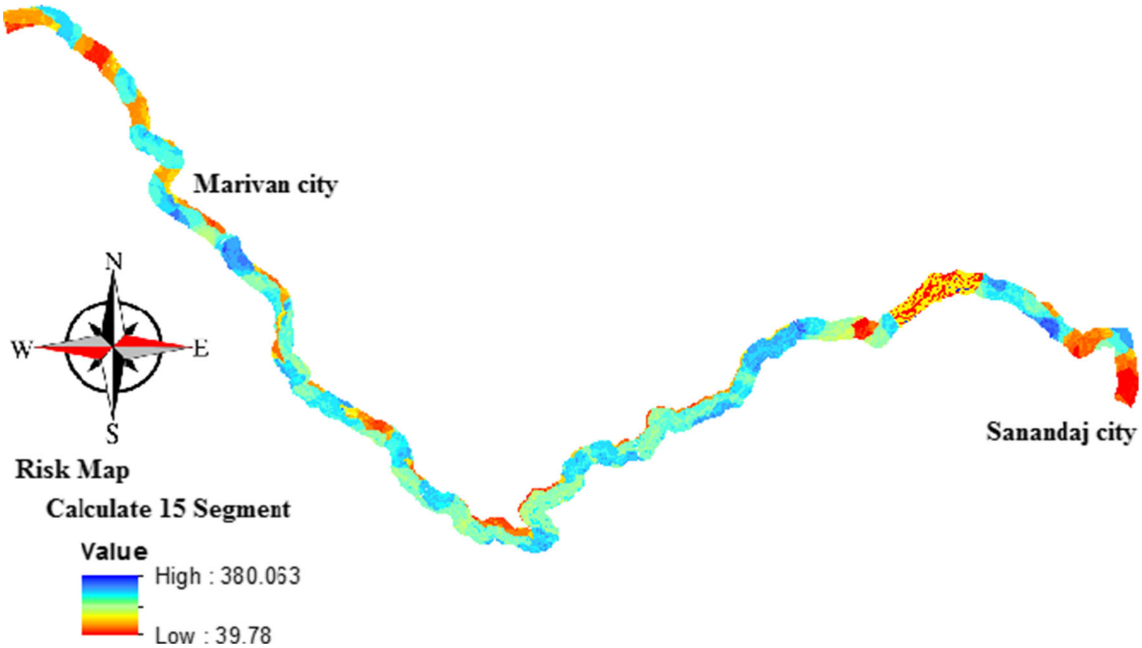


Fig. 8 The final output layer resulting from the integration of layers for the entire road Sanandaj-Marivan

Table 3 List of selected scenarios and their weights

Weight	Different seasons	Volume of drainage	Type of material transported	Scenario
0.060	Spring	> 12,000	Gasoline	Scenario1
0.058	Spring	> 12,000	NAFTA	Scenario 2
0.056	Spring	> 12,000	Kerosene	Scenario 3
0.020	Winter	> 12,000	Mazut	Scenario 4
0.009	Winter	8000–12,000	Mazut	Scenario 5
0.004	Winter	4000–8000	Mazut	Scenario 6

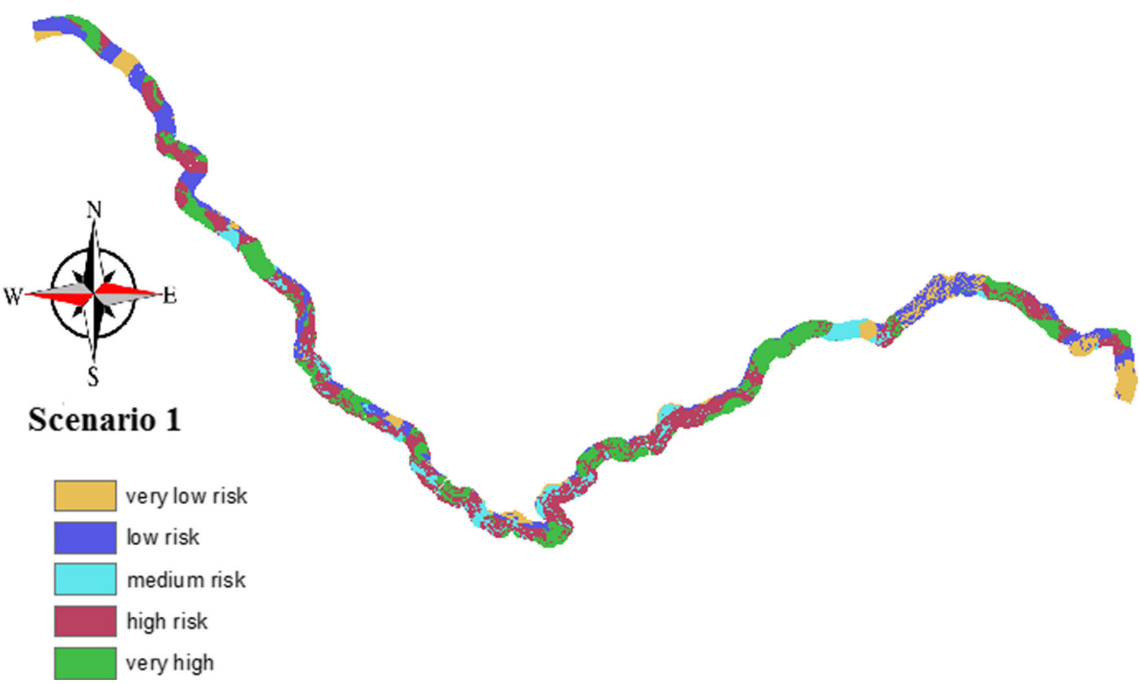


Fig. 9 Map of the consequences of the entire road in scenario 1

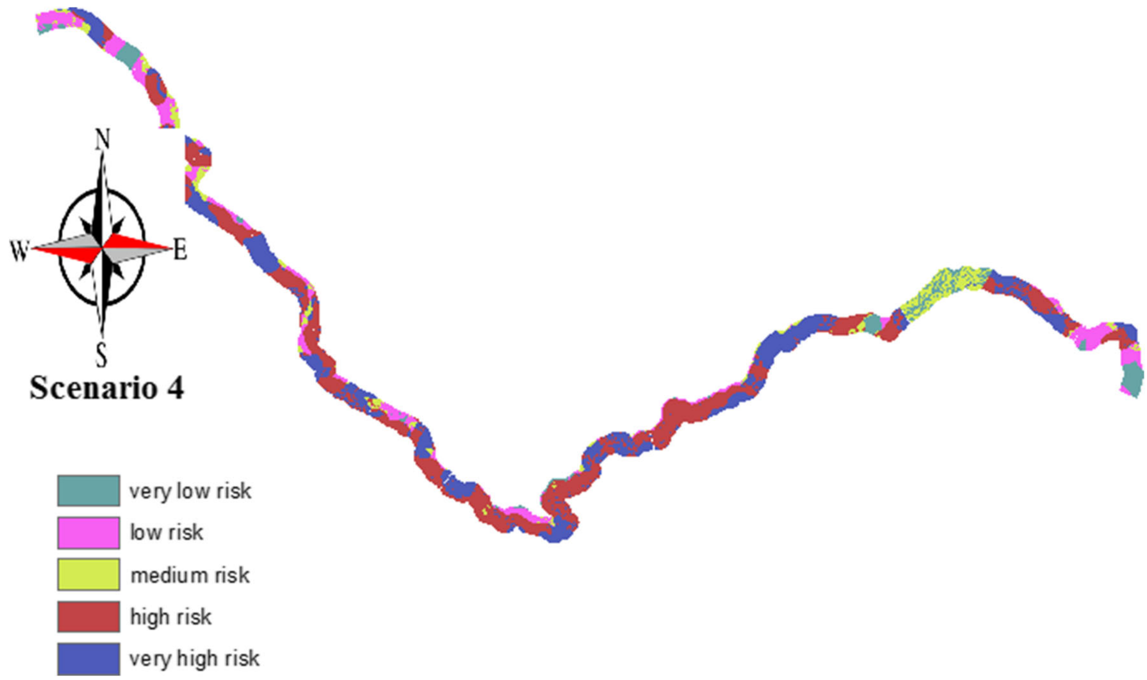


Fig. 10 Map the consequences of the entire path in scenario 4

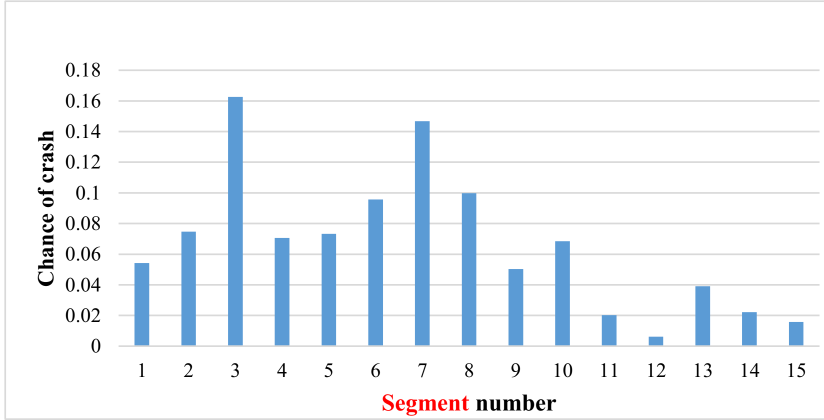
each segment. The geometric characteristics of each segment and its probability of accident are shown in Table 4.

According to Table 4, the slope of the segment is an important factor in calculating the probability of accidents such that the lower slope the segment is, the lower probability of accidents will be. According to Iran's Road Construction Code, the maximum slope in mountainous routes should be 12%, which, according to Table 4, and available statistics, the slope of most of the segments is more than 12%, and it is one of the important factors for truck accidents. Also, the average width of the road in each segment is low, and the segments with very low width are more likely vulnerable to accidents. Also, the arcs are important factors in the occurrence of accidents, and there are many arcs along the entire road, and these arcs intensify the accidents. According to the results, the probability of an accident in segments 3, 7, 8, and 6 are more than other segments, and the probability of accidents in segments 12, 15, 14, and 13 are lower than other segments. The probability of an accident in each segment is shown in Fig. 11.

Table 4 Geometric characteristics and accident probability of different parts of the Sanandaj-Marivan route

Accident probability	The average number of accidents per year	Number of mazes	Average total width	The slope of the average piece	Segment number
0.054	1.46436	10	12	8	1
0.074	2.01809	25	7	8	2
0.162	4.38956	29	10	11	3
0.070	1.90534	50	18	11	4
0.073	1.9764	70	18	30	5
0.095	2.58553	42	6.5	30	6
0.146	3.96128	28	6.5	23	7
0.099	2.69526	23	6.5	23	8
0.050	1.35995	30	6.5	29	9
0.068	1.85059	34	6.5	29	10
0.020	0.54703	20	10	33	11
0.006	0.16444	14	7.5	33	12
0.039	1.05669	10	20	4	13
0.022	0.5983	15	10	5	14
0.015	0.42719	7	10	5	15

Fig. 11 Accident probability of in each segment of the Marivan-Sanandaj road



In order to calculate the consequences of first-order criteria, the initial maps of the four main criteria, including the digital terrain model (DTM), waterways and wells, and their depth, were implemented in GIS, and each layer was cut with a buffer of 800 m. Then, the raster layers related to the main criteria, including slope, drainage density, and the distance from waterways and groundwater, were produced. Figure 12 shows the map of the groundwater level; Fig. 13 shows the map of the slope; Fig. 14 shows the map of drainage density; and Fig. 15 shows the map of distance from waterways for segment 4.

These layers were classified and based on AHP, a weight was allocated to each class, and the final map for each criterion was produced. Table 5 shows the classes and weights of each sub-criterion.

After preparing the layers for each main criterion, they were combined by the index overlap method, and the final map of consequences of the first-order criteria for each segment was produced. By putting all pieces, the consequence map for the entire road was generated. Figure 16 shows the consequence of the first-order criteria for segment 4, and Fig. 17 shows the risk map of the first-order criteria for segment 4. Also, Fig. 18 demonstrates the final consequences map of the first-order criteria for the entire road, and Fig. 19 shows the final risk map of the first-order criteria that is classified into five classes for the entire road.

Figures 20 and 21 show the final risk map for the first category criteria for scenario 1 and scenario 4, respectively.

According to the results, most of the segments with high accident probability are high-risk segments; therefore, there is a direct relationship between the risk of accident and risk, and there is a high risk in any segment with a high accident probability. Also, according to the results and Table 6, the total water pollution risk in the road is distributed as 20% very low, 19% low, 29% moderate, 28% high, and 4% very high. Also, according to scenario 1, 14% of the total area of the study road is very low risk, 23% low risk, 15% medium risk, 6% high risk, and 42% are very high risk. Also, according to the results in terms of scenario 4, 39% of the total area of the study road has a very low risk, 44% low risk, 13% medium risk, and 4% high risk.

According to Table 7 and the results of the risk map for the first category, segments 3, 4, 6, 8, and 9 are at high risk, and segment 7 is very high risk. Also, according to the results and Fig. 18 of the final risk map of scenario 1, segments 2, 3, 4, 5, 6, 7, 8, and 10 are very risky. Based on the final risk map and Fig. 19, with the four scenarios, segment 7 is at high risk.

Generally, according to the results obtained from different parts, segments 6, 7, 8, and 3 were finally identified as the segments with the highest risk of water pollution in the road, respectively; thus, they should be considered for any future road planning and re-construction programs.

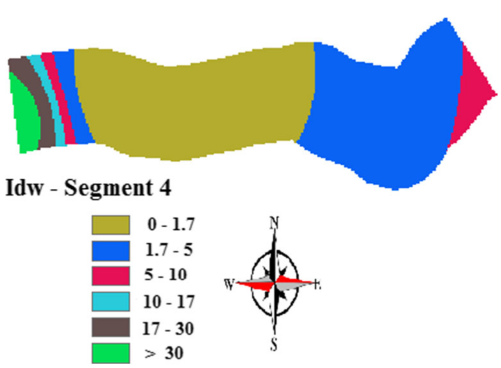


Fig. 12 Groundwater level for the 4th piece

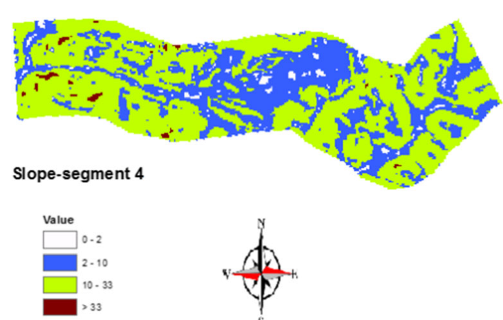


Fig. 13 Slope of the four pieces

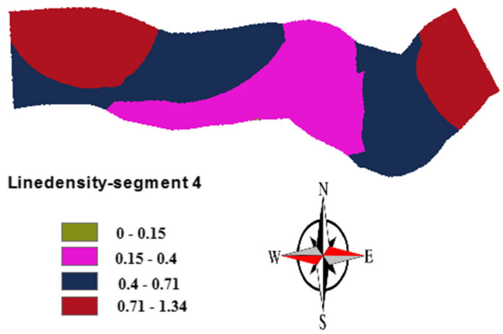


Fig. 14 Drainage density of the fourth piece

Conclusion

Truck accidents during the transportation of HazMat on roads in the vicinity of rivers and streams can potentially cause serious problems to human health and irreparable damage to natural resources. The Sanandaj-Marivan road as one of the main transit routes for petroleum materials in Iran, there has been a great deal of contamination of water and environmental resources due to the accidents of trucks carrying these materials. Risk assessment of water resources pollution is a cost-effective way to quantify the risks and potential consequences of these accidents.

In this study, we assessed the risk of water pollution in the Sanandaj-Marivan road due to the transportation of hazardous substances for group 3 hazardous substances (flammable liquids including kerosene, fuel, gasoline, benzine, argon, liquefied petroleum gas, naphtha) based on ADR classification.

In this study, a risk map was prepared for the entire route by integrating 15 different risk maps into the GIS software using the mosaic tool. The risk categories were then divided into five categories: very low risk, low risk, medium risk, high risk, and very high risk. According to the results obtained by Poisson regression method, segments 3, 7, 8, 6, and 2 had the highest probability of an accident, indicating that segments 7, 8, 6, 5, and 3 were identified as they had the highest risk of contamination for water resources along the road. Segments 2, 4, 10, 9, 1 had medium risk, and segments 13, 11, 14, 15, and 12 had low risk. We conclude that the risk of contamination of water resources in the study area is high. According to the results, it is suggested that segments 7, 8, 6, 5, and 3 should be given special attention as they have the highest risk of contamination of water resources in the Sanandaj-Marivan road.

The results of this study highly indicated that the road Sanandaj-Marivan is very risky to HazMat transportation since its width is low, the slope is high, many arcs in the road, and its vicinity to surface water and groundwater resources. This is in agreement with Vrabel et al. research (Vrabel et al. 2015). Our results can show that other roads in the country may have similar problems, as indicated by Ghazinoori et al. research (Ghazinoory and Kheirkhah 2008).

Also, to reduce the risks and prevent pollution of the entire route, especially high-risk components, it is recommended to create and install barriers, fences, and concrete walls along the riverside road, modify the geometrical design of the route, and manage and control the speed in these areas as having been recommended by Lee (Lee 2014).

This study focused on geometric characteristics of the road, including slope and the number of arcs in the road, as well as two important basin characteristics such as drainage density

Table 5 The classes and weights of each sub-criterion

Weight	Class	Layer name
0.07	0–2	Slope
0.11	2–10	
0.27	10–33	
0.55	> 33	
0.06	0–0.15	Line density
0.10	0.15–0.4	
0.27	0.4–0.71	
0.57	0.71–1.34	
0.68	0–800	Surface water
0.23	800–2000	
0.09	> 2000	
0.41	0–1.7	Groundwater
0.27	1.7–5	
0.15	5–10	
0.10	10–17	
0.04	17–30	
0.03	> 30	

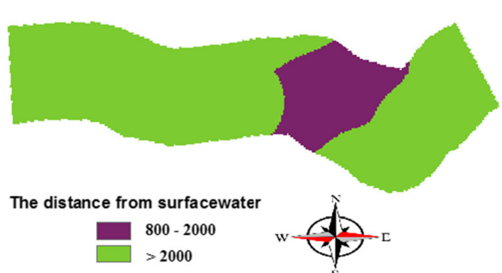


Fig. 15 The distance from the waterway to the four pieces

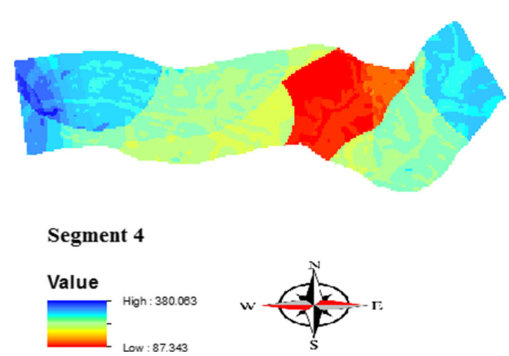


Fig. 16 Consequences map of segment 4

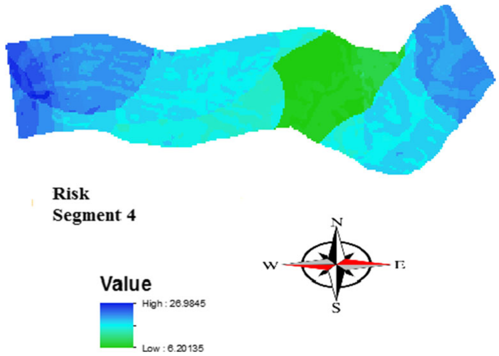


Fig. 17 Risk map of segment 4

and road distance to waterways. The season of the year was considered since the truck accident database showed the majority of the accidents have happened in spring and winter. The selection of season for analysis has received little attention in research (Zhao et al. 2018), even though some have considered day instead of the season (Bruglieri et al. 2014). The methodology used in this study and the combination of the affecting factors on transporting HazMat is unique, and no comprehensive research had been conducted on this issue in the study area.

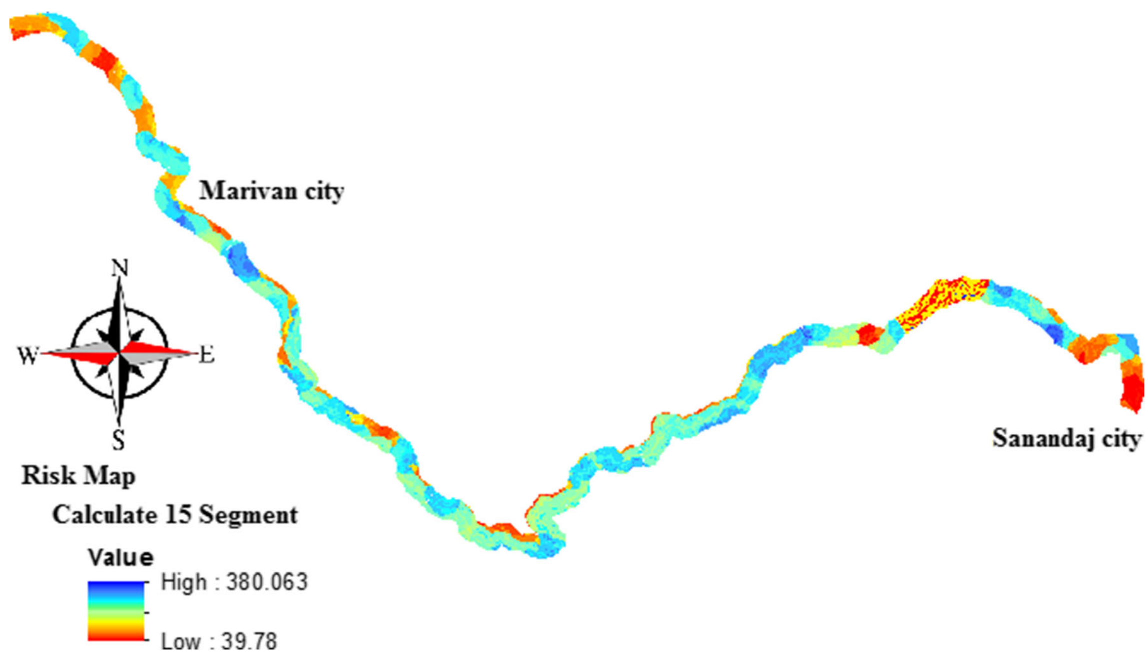


Fig. 18 The final map is the result of the first category criteria for the entire path

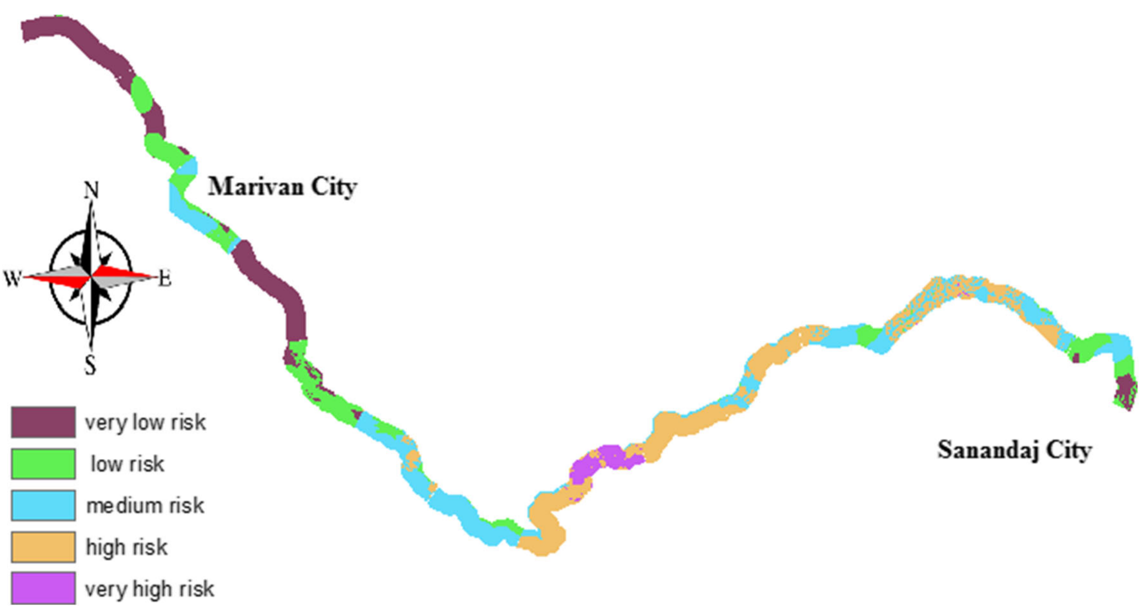


Fig. 19 Ultimate risk map of the Sanandaj-Marivan road for the first category criteria

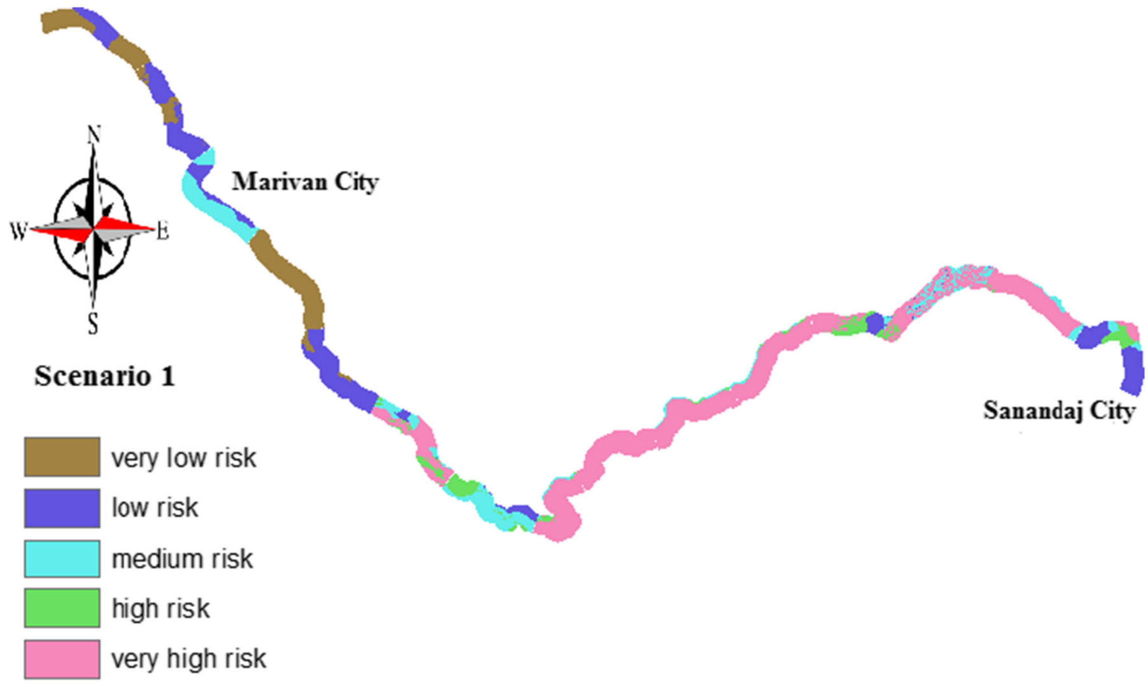


Fig. 20 Risk map with scenario 1 for the Sanandaj-Marivan road

Fig. 21 Risk map with scenario 4 for the Sanandaj-Marivan road

Table 6 Percentage of risk area of the first category criteria and one and four scenarios

	Very high-risk area	High-risk area	Medium-risk area	Low-risk area	Very low-risk area
First category criteria	4	28	29	19	20
Scenario 1	42	6	15	23	14
Scenario 4	0	4	13	44	39

Table 7 Components with varying degrees of risk for the first category criteria and one and four scenarios

	Very high-risk area	High-risk area	Medium-risk area	Low-risk area	Very low-risk area
First category criteria	7	3, 4, 6, 8, 9	2, 5, 10, 13	11, 1, 4	12, 15
Scenario 1	2, 3, 4, 5, 6, 7, 8, 10	–	9, 13	1, 11, 14	12, 15
Scenario 4	–	7	3, 6, 8	2, 4, 5, 9, 10, 13	1, 11, 12, 14, 15

The information and suggestions provided by this study should be taken into consideration by regional water and environmental authorities and other relevant organizations such as road and road transport and urban planning organization. The risk map provided in this study can play an important role in preventing water pollution in the Sanandaj-Marivan route and reduces the risk of contamination of groundwater and surface water resources along this route. It can also greatly reduce the financial costs of fuel truck accidents along the route.

It should be noted that the most important limitation in this study is the lack of a complete database of oil truck crashes in the study area for a period of at least 10 years. In order to improve the performance of the model, it is suggested that in future research, these data should be collected in a database, including oil material type, time of the accident, the exact location of the accident, cause of the accident, and amount of nature leaks. This information can provide a comprehensive insight into the management of environmental issues related to hazardous material transport on the roads.

It is also suggested if data exists, the probability of accidents can be modeled with other regression methods and their results compared with the proposed method in this article. Finally, if data exists, it is recommended to consider other effective factors to calculate the consequences such as wind speed and air temperature and other climatic factors.

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