Presenting a model for management of the oil spillage from oil pipeline (Case study: Karun river)

Mostafa Zaredoost[١*], Jafar Nouri[2], Jamal Ghodousi[3], Reza Arjmandi[3]

1- Ph.D. student of environmental management, Islamic Azad University, Science and Research Branch, IRAN, Tehran (zaredoost@yahoo.com)
2-Full professor of environmental sciences, Islamic Azad University, Science and Research Branch ,IRAN, Tehran
2- Assistant professor of environmental sciences, Islamic Azad University, Science and Research Branch, IRAN, Tehran

Abstract

Oil is a natural wealth for any country. Spillage and distribution of this matter is considered as an environmental crisis. Given that there is oil transmission pipeline network with about 7,000 km in the country, so it is difficult to manage and inspect the lines. GIS and spatial decision-making methods provide powerful tools in order to prioritize the risk of oil spillages from pipelines. This study aims to provide a model of management of oil spillage from transmission lines. In this study, using the expert views (opinions) criteria affecting on the oil spillages from the pipeline were identified. These criteria include the geological feature, environmental features, hydrological features and human factors. Then, in each of the main criteria group, the related sub-criteria were identified. Then, using FAHP each sub-criteria relative to main criteria group as well as each of the criteria relative to the goal (spillage risk) were weighted. After weighting, sub-criteria were integrated using by using a sub linear model based on weights obtained from FAHP in GIS environment and criteria priority map relative to the goal was prepared. Then, maps of the criteria were integrated with each other based on their weights and zonation map of spillage risk in the pipeline route was prepared. The results show that pipeline route has a high sensitivity to spillage from transmission pipeline so that most of limits around the pipeline occurs in a medium to high risk class.

Keywords: Oil Spillage Risk, Environmental Risk, Geographic Information Systems, FAHP method

* Author to whom all correspondence should be addressed: E-mail: zaredoost@yahoo.com

1. Introduction

Oil spillage from oil pipelines and entrance into surface water is one of the issues and problems that in addition to economic risks, have many environmental risks in the aquatic environment. While oil derivatives are absolutely vital to modern society, the oil spillages in surface water are very harmful for the environment, society and economy. The consequences of an oil spillage can be even worse if adequate clearing measures are not adopted quickly. As a result, emergency actions should be conducted when occurring oil spillages to protect the environment and management of spilled materials and this will be practicable only when highly-sensitive locations would be pre-determined (Pincinato, *et al*, 2009). Identifying the areas susceptible to oil spills from pipelines as well as understanding the process of oil leakage into river flow is important in identification of the risk of oil leakage from transmission lines into surface water flow and their entrance into the river flow. Some researchers stated that transmission of pollutants into the aquatic environment is a function of environmental conditions of the area (Ramachandran, et al, 2014). For example, factors influencing pollutant transmission into the aquatic environment such as rivers are the amount and intensity of rainfall, type of geologic formations, slope, aspect, elevation classes (above sea level), forms of drainage network, land use, vegetation (type and density) and soil properties (texture and aggregation) d (Bedri, *et al*, 2014). Environmental impacts caused by the entry of pollutants into aquatic environments have caused the scientific community to research and study in this field. Among the conducted studies in this field are study by Butler *et al* (2014) who investigated the effect of land use in transport of oil materials, and also Tong and Chen (2002) who stated that the transport of pollutants into surface water flow is a function of land use type and environmental factors. Given that most researchers consider transport of pollutants into the aquatic environment as a function of several factors, as a result, multi-criteria decision systems and GIS are efficient tool to identify and zoning sensitive areas and also transport of spilled materials into the surface waters. For applying appropriate multi-criteria decision-making technologies for selecting the decision-making options, there are two main issues, including: 1. Simultaneous integration of views of a group of decision makers, (2) none of the decision makers, are able to allocate a precise quantitative for an option compared to a criterion and thus usually oral quantities or terms are used. Therefore, a technique should be used which able to solve the two above-mentioned problems. The technique must be able to apply for all decision-makers and should be able to allocate an appropriate quantitative value appropriate to oral variables. For this purpose, fuzzy theory is used. In many decision-making problems and engineering these are some uncertainty which can be solved using fuzzy theory. While quantifying and analysis of these issues by the certainty theory is more complicated. Among the AHP benefits are simple calculation, simple relationships between objective, criteria and options as well as simple understand and use of qualitative and quantitative data. Although the purpose of AHP is to sum the expertise views, but conventional or traditional AHP cannot reflect human thought (Karaman et al., 2004). So fuzzy analytic hierarchy process (FAHP), a developed AHP, was used in this study to identify areas susceptible to oil spillages. The purpose of this study is to zone the risk of spillage and transmission of spilled materials from oil pipelines using FAHP and GIS.

2. Case studies

Iran is one of the most oil-rich regions of the world. Most of oil is produced in the Khuzestan province where more than 7,000 km of oil pipelines have been scattered across the province. Since 30% of flowing water is located in Khuzestan province, so far no research has been performed that evaluate the vulnerability of the rivers in this province. The oil pipeline in the northeastern city of Ahvaz was selected as the study area. The length of the pipeline is about 40 km located at between 38º 28' 25"- 31º 15' 56" N and 54º 33' 12"-54º 53' 25" E (Fig. 1).

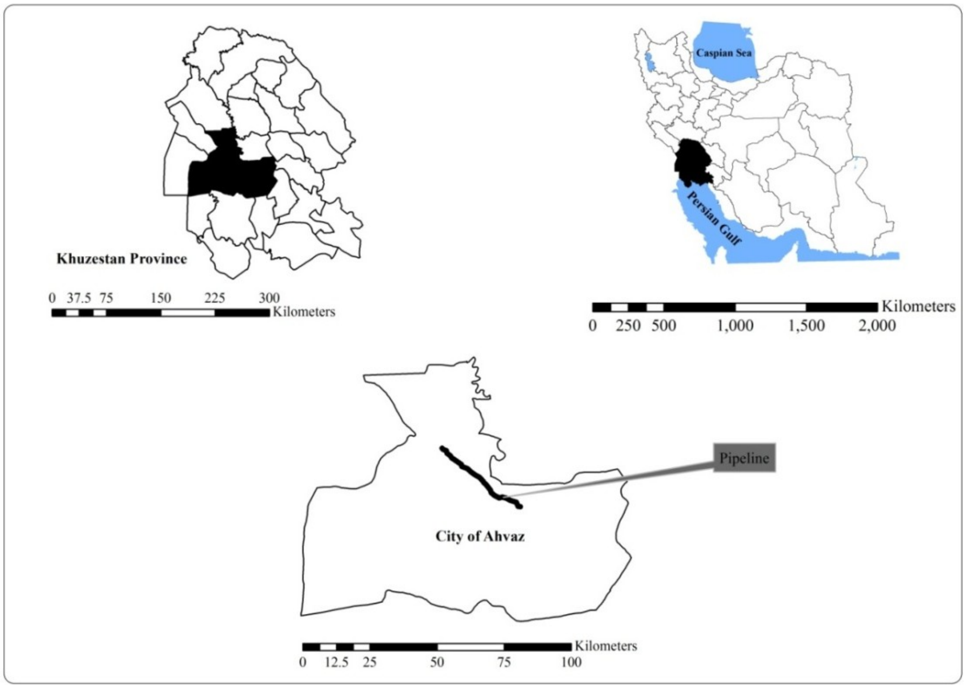

Fig. 1. The geographical location of the study area in Khuzestan province, Iran

3. Research Methodology

Implementation steps of this study are as shown in Figure 2.

- identifying the goal criteria and sub-criteria
- Standardization and weighting of goal criteria and sub-criteria
- Integrating sub-criteria and criteria in order to achieve the goal
- Identifying goal options
- weighting the options to achieve the goal

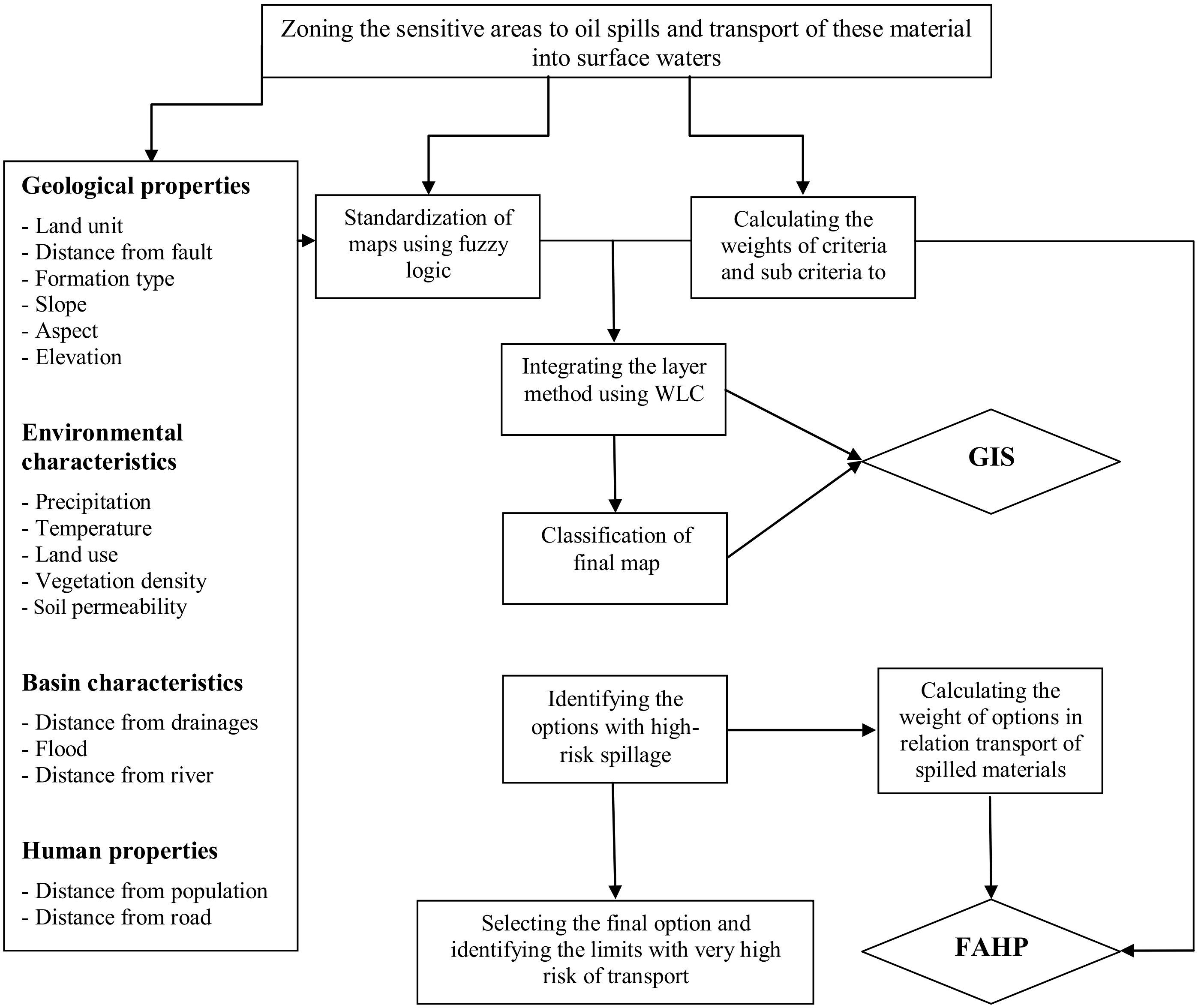

Figure 2. Model flowchart to achieve high - risk zones of oil spillage and transport into surface waters.

3. 1. Identifying the goal criteria and sub-criteria

A number of four key criteria, including geological properties, environmental properties, basin properties and human factors were identified using literature review and the views of experts in order to achieve the study goal. These four criteria include 16 sub-criteria. Tables 1-4 indicate a brief description of the sub-criteria identified in the criteria. In fact, based on the compatibility, each of sub-criteria were fell in fuzzy sets and standardized. Data used in this study includes topographic, geologic, soil, land use and vegetation maps of year 2014, climate data over a 30-year period (1982 - 2014) and satellite images of IRS satellite of the year 2014.

Tables1. Sub-criteria of the main criterion of geologic properties

Sub-criteria	***Suitability description***
Distance from the fault	Distance from the fault
Alluvial formation	Formation type
Slopes higher that 25%	slope

Tables2. Sub-criteria of the main criterion of environmental properties

Suitability description	***Sub-criterion***
Areas with high precipitation	precipitation
Areas with very low and very high temperature	temperature
rangelands	Land use
Low density	vegetation
Areas with low permeability	Soil permeability

Tables3. Sub-criteria of the main criterion of basin properties

Suitability description	***Sub-criterion***
low distance of pipeline from drainage	Distance of pipeline from drainage
High flood potential (very steep slopes)	Flood potential

Tables3. Sub-criteria of the main criterion of human actors

Suitability description	***Sub-criterion***
low distance from population centers	Distance from population centers
Low distance from roads	Distance from roads

3. 2. The standardization of goal criteria and sub-criteria

Fuzzy standardization was used to unify quantitative criteria units as well as to map qualitative criteria. Fuzzy Standardization was performed in the range of 0-1. This means that the number 0 and 1 had the lowest and the highest suitability for areas vulnerable to the risk of oil spillages from pipelines. All the maps of the criteria with cell size of 5 m were converted to a raster format. In this study, the sub-criteria were fuzzed using a set of fuzzy functions of Idrisi software (Table 5).To make fuzzy the most of sub-criteria, Sigmoidal functions set were used. In some sub-criteria there is no relationship between the values and Sigmoidal functions set, in this situation the user-defined functions are more appropriate (Eastman, 2003).In this study, the qualitative criteria were fuzzed based on user-defined functions. In Figure 3, control points used in sigmoidal functions are shown. When the sub-criterion values are uniformly increasing or decreasing, only two control points are defined in fuzzy set, while when sub-criterion values are symmetrical, all the 4 control points are defined in the fuzzy set (Eastman, 2003).

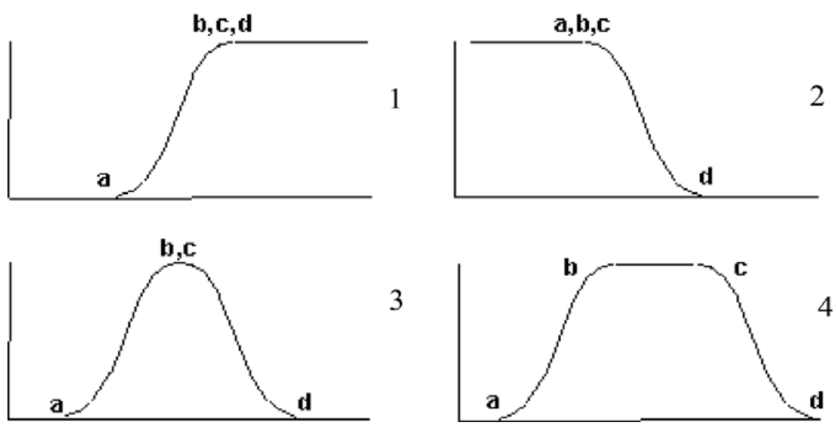

Fig. 3. Control points in Sigmoidal functions (1 – Monotonically increasing, 2 – Monotonically decreasing, 3 and 4 – Symmetric curves).

3. 3. weighting and prioritization of goal criteria and sub-criteria

Gamous (2009) states that by generalizing the paired comparison method, some methods have been presented in which fuzzy numbers are used to indicate the relative weight of criteria to goal, sub-criteria to criteria and options to criteria and sub-criteria. Among these methods are those provided by Buckley (1985) and Chen (1992). These methods are some systematic approaches for selecting options and judging about issues using concepts of fuzzy theory set and analysis of hierarchical structure. Also, there is an extensive evaluation related to these techniques in Karaman studies (2004). In This paper, FAHP was done using method of Development Analysis by Chang. This method (Chen, 1992) was applied because of having easier steps compared to other methods. FAHP algorithm based on Development Analysis of Chang is as follows:

Step 1. Developing a hierarchical structure for the problem (Figure 2)

Step 2: Defining of fuzzy numbers to perform paired comparisons (Table 5)

Step3: Determining the paired comparisons matrixes and implementing group judgments (Eq. 1) (using Table 5) (Gamous, 2009).

$$A=\begin{bmatrix} 1 & a_{12} & \rightarrow & a_{1n} \\ a_{21} & 1 & \rightarrow & a_{2n} \\ \downarrow & \downarrow & \rightarrow & a_{1} \\ a_{n1} & a_{n21} & \rightarrow & 1 \end{bmatrix} \quad (1)$$

Table. 5. Fuzzy numbers corresponding to the preference and importance of paired comparisons (Gamous, 2009)

Triangular fuzzy number	***Linguistic expression to determine the preferred option or the importance of the criteria and sub-criteria***
$(\frac{5}{2}, 3, \frac{7}{2})$	Preference or importance of full and absolute
$(2, \frac{5}{2}, 3)$	Very stronger preference or importance
$(\frac{3}{2}, 2, \frac{5}{2})$	Stronger preference or importance
$(1, \frac{3}{2}, 2)$	Low preference or importance
$(\frac{1}{2}, 1, \frac{3}{2})$	approximately equal preference or importance
$(1, 1, 1)$	Exactly equal preference or importance

Step 4: calculating the relative weights of the criteria and sub criteria (Table 5) (a Cheng development analysis method) (Gamous, 2009).

Step 5: Combining sub-criteria to achieve criteria and integration of criteria based on the weights derived from Cheng development analysis method using (WLC) (Malchovski, 1999) In order to identify areas vulnerable to the risk of oil spillages from pipelines.

3. Results and Discussion

3.1. Weighting of goal criteria and sub-criteria

Based on the results obtained from the weighting of criteria and sub- criteria using method FAHP, The highest weight in criteria group of geological features is belonged to the sub criteria of distance from the fault. This sub criteria has more than half of the value of this criterion. In case of sub criteria of environmental features, the soil sub-criterion has the highest value. This sub-criterion has more than half of the value of the criterion of environmental features. In the criterion of hydrological properties of the transmission line route, two sub-criteria including distance from drainage network and flood potential were weighted. Based on the results, the sub-criterion of including distance from drainage network has a higher weight compared to flood potential sub-criterion. Then, the sub-criteria were weighted in human factors criterion. Based on the results obtained, the highest weight in this criteria group is belonged to distance from the communication network, and the highest weight is belonged to distance from the fault. After determining the weight of each of sub-criteria relative to main criteria, the four main criteria identified were weighted relative to the goal. Results of FAHP analysis in relation to weighting the goal criteria showed that the highest weight is belonged to the criteria of geological and environmental features followed by hydrological features and human factors (Figure 6).

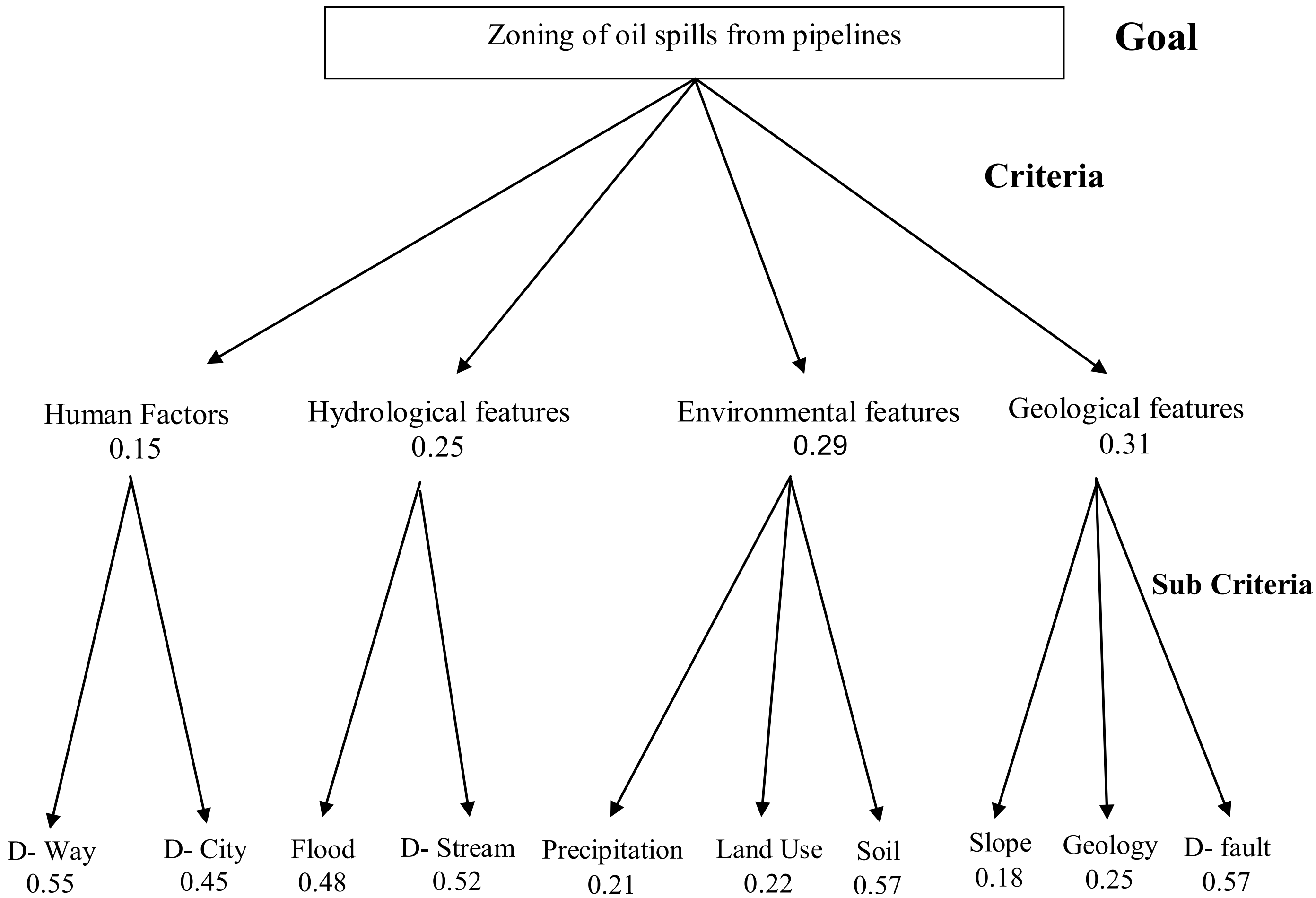

Fig4. Hierarchical structure of the zoning oil spills from pipelines

3-1. mapping and standardization of sub-criteria

Table 6 shows the results of standardization of sub-criteria. After mapping each of the sub-criteria, their values ranged from 0 to 1. Control point a shows the value 1 and control point d indicates the value 0. Points b and c show values between 0 and 1 (Table 6).

Table6. Criteria, sub-criteria and the relative weight with membership function form, fuzzy membership function type

Main criteria	***Sub-Criteria***	***Weight***	***Control point***				***Type of fuzzy function***	***Shape of fuzzy membership***
			a	b	c	d		
Geological features	Distance from the fault	0.57	2084	*	*	15081	Sigmoidal	Monotonically Decreasing
	Geology	0.25	Conglomerate	*	*	Clastic	user_defined	user_defined
	Slope	0.18	0	*	*	26	Sigmoidal	Monotonically Increasing
Environmental features	Soil	0.57	Heavy	Medium	Light	Very light	user_defined	user_defined
	Land Use	0.22	Pasture	Bare	Farm Land	Urban Land	user_defined	user_defined
	Precipitation	0.21	215	*	*	218	Sigmoidal	Monotonically Increasing
Hydrological features	Distance from streams	0.52	2530	*	*	0	Sigmoidal	Monotonically Decreasing
	Flood	0.48	Low	Medium	High	Very High	user_defined	user_defined
Human Factors	Distance from city	0.45	10550	*	*	0	Sigmoidal	Monotonically Decreasing
	Distance from way	0.55	2495	*	*	0	Sigmoidal	Monotonically Decreasing

3-2 integrating the sub-criteria based on weights obtained by FAHP

After weighting the sub-criteria for each of the main criteria, the sub-criteria were integrated with each other based on Equations 2 - 5 and the map of each criterion was prepared (Fig. 7).

$$Geological = Distance\ from\ the\ fault\ (0.57) + Geology\ (0.25) + Slope\ (0.18) \qquad (2)$$

$$Environmental = Soil\ (0.57)\ +\ Land\ Use\ (0.22)\ +\ Precitation\ (0.21) \tag{3}$$

$$Hydrological = Distance\ from\ streams\ (0.52)\ +\ Flood\ (0.48) \tag{4}$$

$$Human\ factors = Dis\ tance\ from\ way\ (0.57)\ +\ Distance\ from\ city\ (0.22) \tag{5}$$

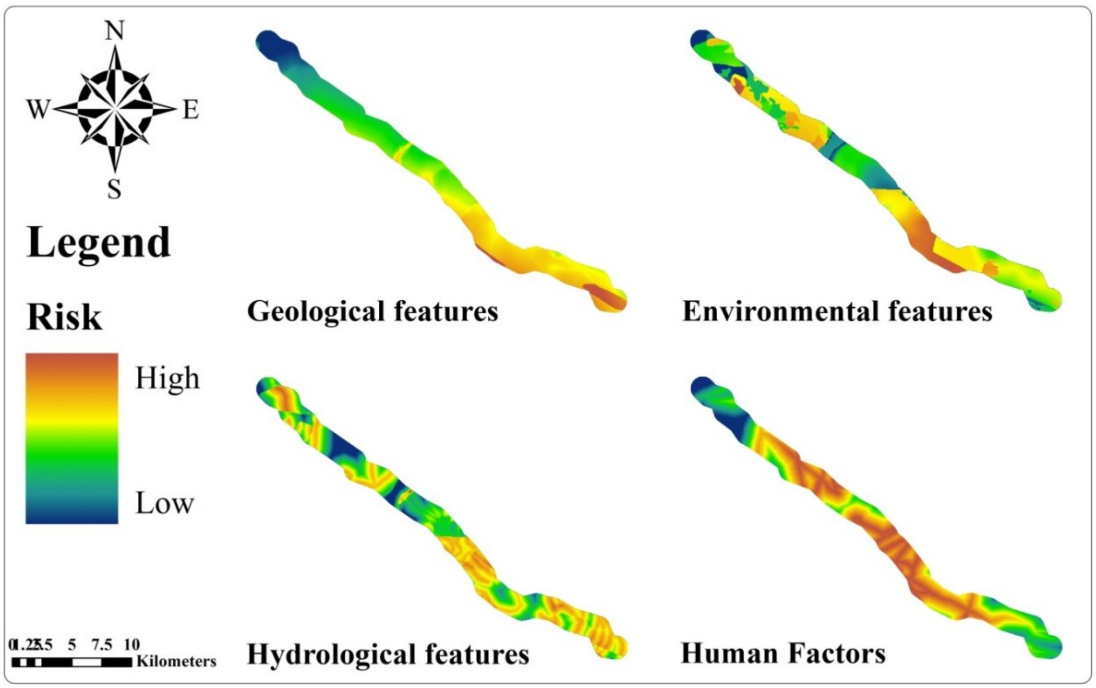

Figure 7. Standardized map of goal criteria

3. 3. Integrating of criteria based on the weights derived from FAHP method for zoning spillage risk

After determining the weight of each of the criteria relative to the goal, the maps were combined as in Equation 6 The obtained map shows the areas sensitive to spillage risk around the pipeline.

$$Prioritize = Geologycal\,(0.31) + Environmental\,(0.29) + Hydrological\,(0.2 + Human\,factors\,(0.15) \quad (6)$$

After integrating, values of the final map shows the spillage risk from the pipeline. Then, using the mean and standard deviation of values of risk map, a map of the spillage risk was zoned in 5 classes. These classes include very low, low, medium, high and very high spillage risk. Based on the classified map, classes with high and very high risk of spillage constitute a significant area of limits of transport line. These classes are often continuous located at southeast end of the transport line (Figure 8).

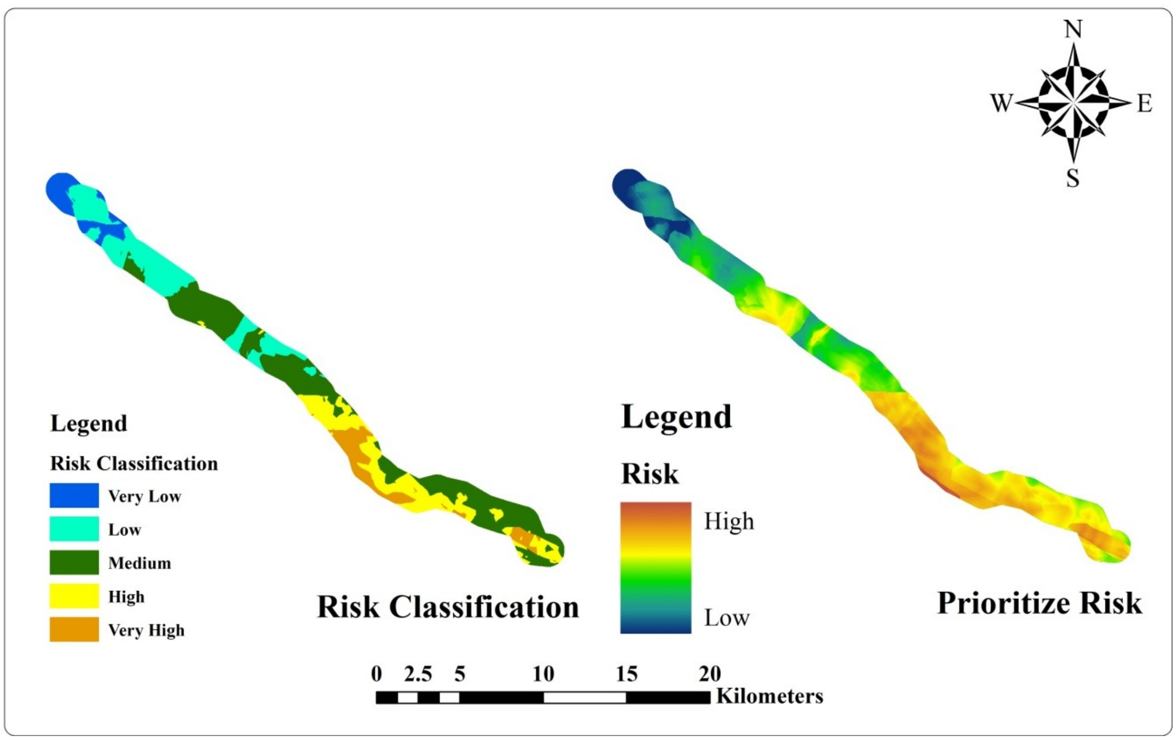

Figure 8. Zoning the spillage risk of pipeline limits

3. 4. Discussion

In this study, using multi criteria decision making and GIS methods, the limits around the oil pipeline was zoned based on spillage risk. Due to the linearity of the flow route of oil, GIS is a powerful tool to identify areas vulnerable to the spillage risk in the pipeline route. In the past, the studies of identifying the risk mainly were related to roads (Anavberokhai, 2008).In this study, the spillage risk of pipelines in the risk limits of pipes was evaluated, while it is often a study is conducted in order to optimize the pipeline routing using multi-criteria decision-making techniques and capabilities of GIS. In studies of Rowland (2005), Gaddy, (2000), Delavar & Naghibi, (2003), Iqbal, et al, (2006), Montemurro, et al, (1998), Yildirim, et al, (2008), Yildirim & Yomralioglu, (2007) and Rowland, (2005) the focus is on optimal routing. In most of these studies often economic issues is considered and environmental issues and environmental risks are often neglected. Feizlmayr & Mckinnon (1999) in a study considered environmental protection as a criterion to choose the optimum routing. With regard to the comparison of our results with other studies in relation to issues of prevention of oil spillages from pipelines, this study can be considered a comprehensive investigation.

4. Conclusion

In this study, using the expert views, criteria related to oil spillage from oil pipelines were collected. Expert opinions were used in the weighting of criteria and sub criteria. The results of the spillage risk show that the area has a high sensitivity to break of oil pipeline and oil spillage. More than half of the limit space of pipeline has a moderate to high sensitivity. According to the results of this study, classes with high sensitivity require appropriate management actions. Given that oil pipelines in Iran have been routed in past years, and lack of attention to environmental issues and natural hazards on their routing, As a result, studies such our study is considered as a solution to identify sensitive areas and provides a proper tool for managers.

References

I. O. Anavberokhai: *Introducing GIS and Multi-Criteria analysis in road pah planning process in Nigeria. MsC Thesis, University of Gavle, Department of Technology and Built Environment.*

Z. Bedri, A. Corkery, J. J. O'Sullivan, M. X. Alvarez, A. C. Erichsen, L. A. Deering, K. Demeter, G. M. P. O'Hare, W. G. Meijer, B. Masterson: *An integrated catchment-coastal modelling system for real-time water quality forecasts. J. of Environmental Modelling & Software,* May 2014, 458-476.

J. J. Buckley: *Fuzzy hierarchical analysis. J. of Fuzzy Sets and Systems,* Apr 1985, 187-195.

S. Butler, T. Webster, A. Redden, J. Rand, N. Crowell, W. Livingstone: *Using Remote Sensing to Identify Changes in Land Use and Sources of Fecal Bacteria to Support a Watershed Transport Model*. J. of *Water*, Jan 2014, 1925-1944.

S. J. C. Chen, L. Hwang: *Fuzzy Multi Attribute Decision Making: Methods and Applications. New York: Springer-Verlag,* 536pp

M. R. Delavar, F. Naghibi: *Pipeline routing using geospatial information system analysis, Στο ScanGIS', The 9th Scandinavian Research Conference on Geographical Information Science, 4-6 June, Espoo, Finland – Proceedings*, 2003, 203 – 213.

J. R. Eastman: *IDRISI for Windows Users Guide Version Kilimanjaro, Clark Labs for Cartographic Technology and Geographic Analysis, Clark University,* 2003.

A. H. Feizlmayr, C. McKinnon: *Lower costs, environmental protection drive future pipeline technologies. J. Oil & Gas*, 1999, 83-89.

D. E. Gaddy: *GIS-controlled workflow. J. Oil & Gas*, Jul 2000, 15 – 34.

A. T. Gumus: *Evaluation of hazardous waste transportation firms by using a two step fuzzy-AHP and TOPSIS methodology*. J. *Expert Systems with Applications*, Aug 2009, 4067–4074.

M. Iqbal, F. Sattar M. Nawaz: *Planning a least cost gas pipeline route: a GIS & SDSS integration approach. J. Στο Proceedings of International Conference on Advances in Space Technologies, Εκδόσεις IEEE*, Sep 2006, 126 – 130.

C. Kahraman, U. Cebeci, D. Ruan: *Multi-Attribute Comparison Of catering Service Companies using fuzzy AHP: The case of Turkey. J. International Journal of Production Economics*, 2004, 171-184.

J. Malczewski: *GIS and Multi-criteria Decision Analysis. J. John Wiley & Sons, New York*, 1999, 392 pp.

D. Montemurro, S. Barnett, T. Gale: *GIS-Based Process Helps TransCanada Select Best Route for Expansion Line. J. Oil & Gas Journal*, 1998, 63-71.

F. L. Pincinato, P. S. Riedel, J. C. C. Milanelli: *Modelling an expert GIS system based on knowledge to evaluate oil spill environmental sensitivity. J. Ocean & Coastal Management*, 2009, 479–486.

R. Ramachandran, P. Ramachandran, K., Lowry, M. L. Hartwig, M. L. Kremer: I*mproving science and policy in managing land-based sources of pollution. J. Environmental Development*, Oct 2014, 4–18.

A. Rowland: *GIS route selection analysis for Oil and Gas exploration using Multi- Criteria Decision Analysis- Case Study of the Oil and Gas Producing area of the Niger Delta in Nigeria, MSc Thesis, University of Greenwich, London.* 2005.

S. T. Y. Tong, W. Chen: *Modeling the relationship between land use and surface water quality. J. Journal of Environmental Management*, Feb 2002, 377 – 393.

V. Yildirim, R. Nisanci, T. Yomralioglu, B. Uzun: *Raster-based GIS data guide economic pipeline construction. J. Oil & Gas Journal*, Dec 2008, 62-68.

V. Yildirim T. Yomralioglu: *GIS Based Pipeline Route Selection by ArcGIS, ESRI Users Group Conference, Accessed.* 2007.