Research Article

Pipeline Risk Assessment Using GIS

Jafar A. Ali [a,*], Loghman Khodakarami [b], Murad S. Ahmed [c]

Department of Petroleum Engineering, Faculty of Engineering, Koya University, Koya, Kurdistan Region, Iraq.

[a] jafar.dalo@koyauniversity.org, [b] loghman.khodakarami@koyauniversity.org, [c] murad.00005862@gmail.com

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Abstract
Long-distance energy pipelines are subject to risks of repeated hazards and posing pipeline safety problems. Hazards that may attack the pipelines are environmental and human activities. In this study, the risks of hazards on pipeline were assessed using Geographic Information System (GIS) as research on pipeline risk assessment using GIS is quite limited. Satellites help to monitor pipelines from space. The study spatially analyzes the risks that a pipeline encounters and the Kurdistan oil pipeline from Taq Taq oil field to Peshkhabur was used as a case study. Six criteria including distance to cities and villages, rivers, roads, slopes, and temperature in cold and hot weather were considered. Weight is given to each criterion; a maximum of 37.5% for human activities and a minimum weight of 12.5% for slope. The calculations were carried out spatially rather than through statistical operations. Three sets of maps were obtained for each criterion with different units. Then the maps were overlayed to represent a single map and the units were standardized using Fuzzy membership. The results show the risk level of each criterion along the 270 km length of the Kurdistan national pipeline.

Keywords: Risk Assessment, Pipeline, Geographic Information System, GIS, Fuzzy Logic.

1. Introduction
Pipelines are energy lifelines, making almost every daily activity possible. Pipelines play a huge role in everyday life and are essential to industries. It is a network that delivers the nation's crude oil and petroleum products reliably, safely, efficiently, and economically (Gilbert, n.d.). Pipeline risk assessment is a science that has been vital in petroleum industry and has been growing adversely due to the growth of pipeline numbers in the world. A necessary point on which these risk-assessing studies rely is the statistical review of occurred accidents causes which clarifies and helps to investigate, manage, and monitor the pipelines (Jafari et al., 2011). Satellites help to monitor pipelines from space. This timely pipeline monitoring system will detect leaks, environmental conditions of the pipeline, rivers, faults, and many other parameters that can act as a risk to the pipeline system overall, through daily pipeline monitoring. Geographic Information System (GIS) can be used to monitor and assess the risks in the selected pipeline (Mittal, 2018). It is unreasonable to think of pipelines as being 100% safe. Thus, the main question to confront is whether the pipeline is safe enough, and will the public accept the risk associated with the operation of the pipeline (Wateya et al., 2022). Studies that have been conducted so far regarding energy transmission risk assessment are performed by different approaches, and each of these methods highlights a certain parameter in risk assessment.

Cross-country pipelines could be assessed using an integrated model. Such a model considers technical analysis, socioeconomic impact analysis and environmental impact analysis in an integrated framework to select the best from a few alternative feasible projects (Dey, 2002). In presenting different parameters for risk assessment of chemical substances hazards Fuzzy logic approach was used to rapid the assessment and relative ranking (Paralikas & Lygeros, 2005). GIS provides a large number and a variety of analytical functions that are capable of replacing manual and traditional methods of route planning. It is a powerful tool to integrate thematic layers in an automated environment to compute the possible safest route with associated costs (Ali & Khodakarami, 2015). The crude pipelines are environmentally sensitive particularly if they cross populated areas, hills, fields, forests, rivers, etc. Rivers not only contribute to higher humidity rates but also have a direct effect on the pipeline such as damages caused by flooding. Pipelines that cross rivers and streams are more vulnerable to breaks when heavy rain and floods occur (Earthworks, n.d.). Besides those Kurdistan pipelines (Figure 1) encounters very high temperature and low-temperature environments in different seasons of the year.

In this paper the risk assessment for the Kurdistan pipeline is carried out, the main criteria were considered and weight has been given to each criterion. The main aim of the case study should be finding out the potential accidents, analysis of the causes as well as improvements to reduce the risks. And the objectives of the case study are to determine the risks of the proposed oil pipeline, using GIS and ArcMap software programs to take satellite image data and spatially analyze them.

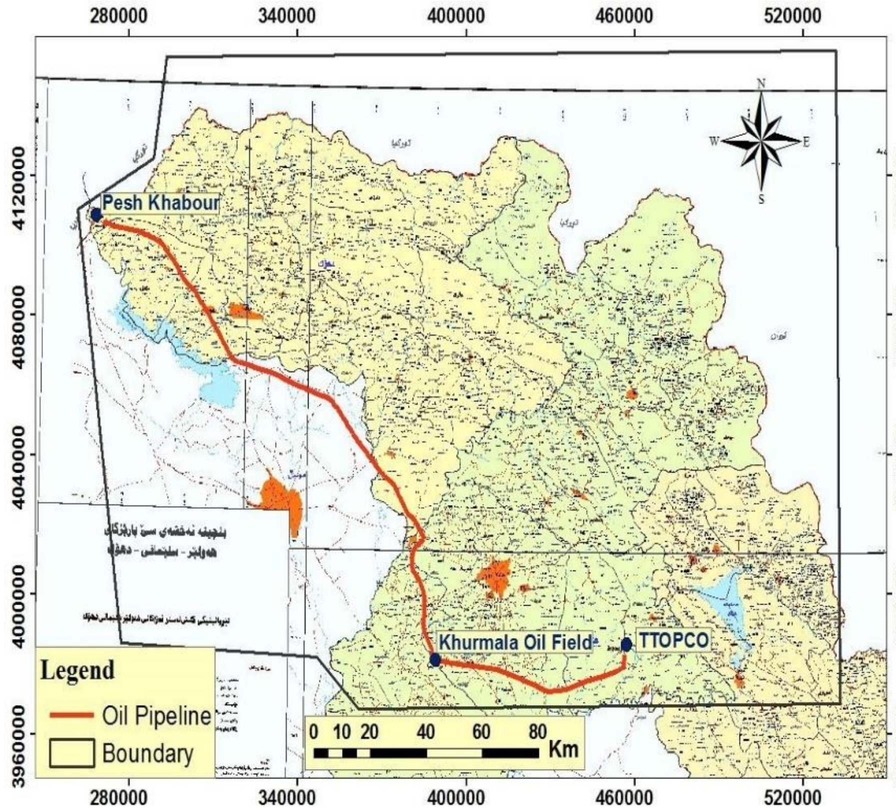


Figure 1. Kurdistan oil pipeline (MNR, 2013).

2. Cloud Model Theory

The cloud model theory is an extension of the Fuzzy set theory, which considers randomness by randomizing the Fuzzy membership (Li et al., 2021). The Fuzzy Membership tool reclassifies or transforms the input data to a 0 to 1 scale based on the possibility of being a member of a specified set (Ross, 2010). 0 is assigned to those locations that are not a member of the specified set, 1 is assigned to those values that are a member of the specified set, and the entire range of possibilities between 0 and 1 are assigned to some level of possible membership, the larger the number, the greater the possibility.

The input values can be transformed by any number of functions and operators available in the GIS extension that can reclassify the values to the 0 to 1 possibility scale. However, the Fuzzy Membership tool allows you to transform continuous input data based on a series of specific functions that are common to the fuzzification process. The membership function is defined on the unit interval [0,1], for example, the Fuzzy Linear membership function transforms the input values linearly on the 0 to 1 scale, with 0 being assigned to the lowest input value and 1 to the largest input value. All the in-between values receive some membership value based on a linear scale, with the larger input values being assigned a greater possibility, or closer to 1 (Ross, 2010).

3. Spatial Data Used and Preparation

The following spatial data used in this study; digital elevation map, the geographical distribution map of the oil pipeline in the Kurdistan Regional Government, spatial distribution map of rivers, the location map of cities and villages, road route map, and Landsat-8 satellite images are the spatial data used in this study.

As there is not any specific spatial data showing the exact location and route of the case study pipeline, or any other raw data to be used in this manner. The pipeline path map has been mapped in 2013 by the Ministry of Natural Resources (MNR). In the current study, the following criteria were considered, human activities, distance from rivers and roads, slope, land surface temperature and aspect. The procedure was as follows:

3.1. Georeferencing

Georeferencing is required to assign real-world coordinates for every spatial data. It is the process of having a digital image for the location. The geographic information system is added to an image to place it in the exact location in real life. There are two methods of georeferencing. The UTM method was used in this study to start building data. Universal Transverse Mercator map projection is widely used nowadays. The projection divides the earth into 60 zones, each zone is 6-degree segment. Kurdistan UTM is 38 (Hill, 2009).

3.2. Digitizing Pipeline Route

After georeferencing the path of the pipeline, it is digitized. Pipeline Route Digitizing in GIS is converting geographic data either from a hardcopy or a scanned image to vector data by tracing the features. During the Digitizing process, features from traced map or image are captured as coordinates in a line format.

3.3. Slope

The slope tells us the gradient or steepness of each cell in the raster surface. It's a norm that the lower slope the flatter the terrain while the higher the slope the steeper the terrain. The output slope raster can be presented in two units' degrees or percent. The digital elevation model was used to create a slope map which had been downloaded from the USGS. Using Arc GIS software, it was established that the DEM used in this investigation contains no geometry errors.

3.4. Human Activities (Cities, Villages, and Roads)

Steps for digitizing cities, villages and roads include georeferencing the MNR map, and then overlaying the digitized pipeline route on the map with a 3 km buffer. Finally visual interpretation of 260 km pipeline route and digitized location of the human activities.

3.5. Rivers

There is no map or data illustrating all the rivers that the proposed pipeline passes through. For the sake of data for this criterion all the rivers of the Kurdistan region have been computed and the case study boundary has been set. The first step followed to compute the rivers was using the digital elevation model (DEM). It is a 3-dimensional (3D) representation of a terrain's surface. Using these DEMs were acquired, and those elevations were extracted that would lead to the formation of rivers using a hydrologic tool.

3.6. Land Surface Temperature

Several methods for calculating land surface temperature from satellite images. The single-band method, multi-band method, and multi-angle method are three of the most well-known and extensively utilized methods. A single window algorithm, which is one of the multi-band methods of determining the ground surface temperature, is employed in this work (Chen et al., 2017; Li et al., 2013). Landsat-8 satellite images were utilized to create a land surface temperature map in this study. The US Geological Survey website has been used to download Landsat-8 satellite images ("EarthExplorer", n.d.). Landsat-8 is the eighth satellite from the Landsat series, was launched on 11 February 2013. The Thermal Infrared Sensor (TIRS) and the Operational Land Imager (OLI) equipment are carried by Landsat-8.

4. Results and Discussion

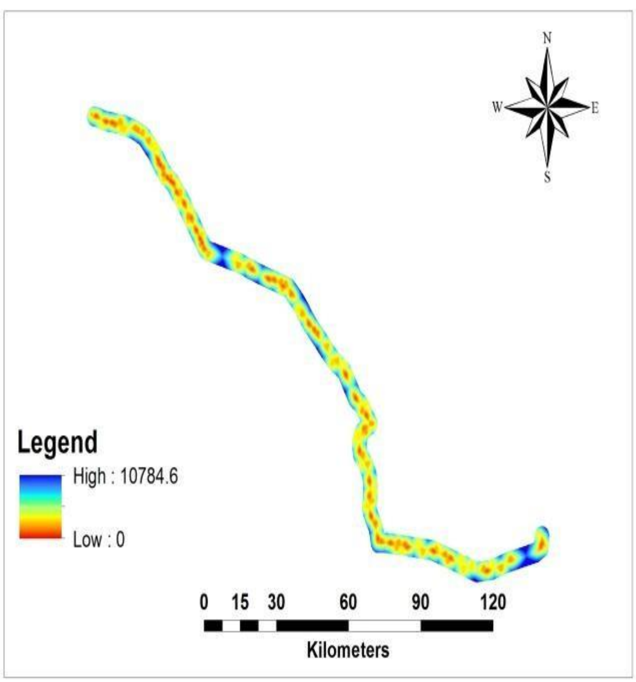
The weighted risk factors on the pipeline are formed by identifying risks on each criterion and then overlaying all these criteria on a single map to show the overall risks along the pipeline. This has been done according to the working principles of the raster-based network analysis algorithm. Therefore, risk factors at every point along the pipeline will be assessed and determined accordingly. A spatial analysis model will be used for implementing and assessing the risk factors. As has been mentioned in the methodology, firstly all the parameters and criteria were identified and mapped, then AHP and Fuzzy logic have been used to weigh and standardize each criterion individually. In a result of performing the steps mentioned these maps were acquired. It is worth mentioning that for mapping the criteria, human activities and rivers, Euclidean formula was used.

Each map belongs to an individual criterion. Each criterion has values of a range, this range of values represents the risk values of each criterion. In the next step, these values will be standardized by Fuzzy logic to acquire a standard range of values. As it has been ordered and aligned previously. In other words, considering that the spatial distribution map of the produced criteria has different dimensions and different measurement units, therefore, they cannot be overlayed. Therefore, in order to homogenize the scale of all criteria and make their units similar, all criteria are standardized and unscaled using the Fuzzy method, and the cell size of all layers has been equalized.

4.1. Human Activity

Human Activity is one of the main criteria of this project as it is the most effective criterion having a weight of 37.5% as the most priority risk. This criterion was created by mapping villages, cities, and roads places in a buffer of 3 km from the pipeline. The value of human activity distance ranged from 3000 to 0 meters to the pipeline. One of the most active places along the pipeline route has the highest risk at a location of 224 km from Taq Taq Oil Production Company (TTOPCO). The point with the least activity is 190 km from TTOPCO. Human activities hazard along the pipeline is presented in the map shown in Figure (2). Figure (2) illustrates the level of risk associated with the oil pipeline caused by human activities. Figure (2a) displays the risk map prior to standardization with the Fuzzy method. Values on this map range from 0 to 10784.8; larger numbers denote higher risk in terms of human activities, while smaller numbers denote lower risk in this regard. In other words, high numbers suggest a high level of habitation near the oil pipeline.

Figure (2b) shows the risk associated with oil pipelines from human activity. Its scale is standardized using the Fuzzy approach, and its possible values range from 0 to 1. Large numbers on this map denote more risk from human activity. However, the standardized human activities (Figure 2b) was multiplied by the human activities weight 37.5, then the results were divided by 100 to produce Figure (2c).



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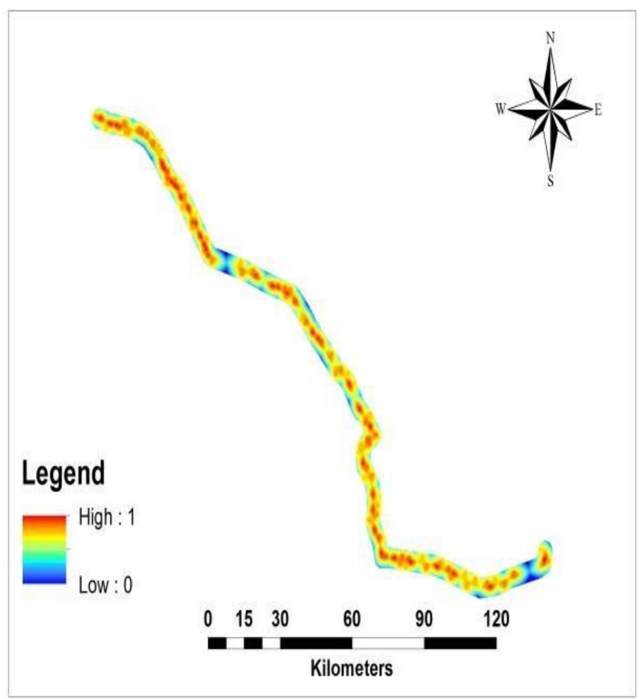

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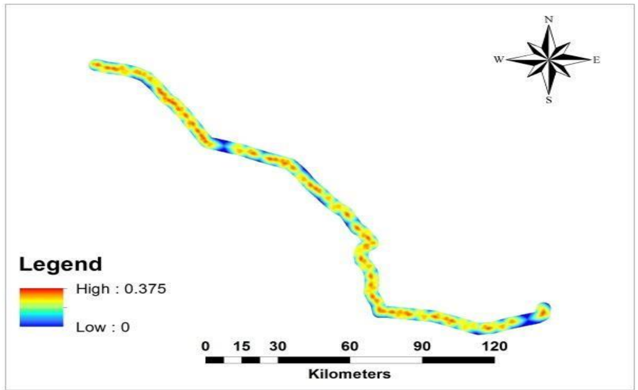


(c)

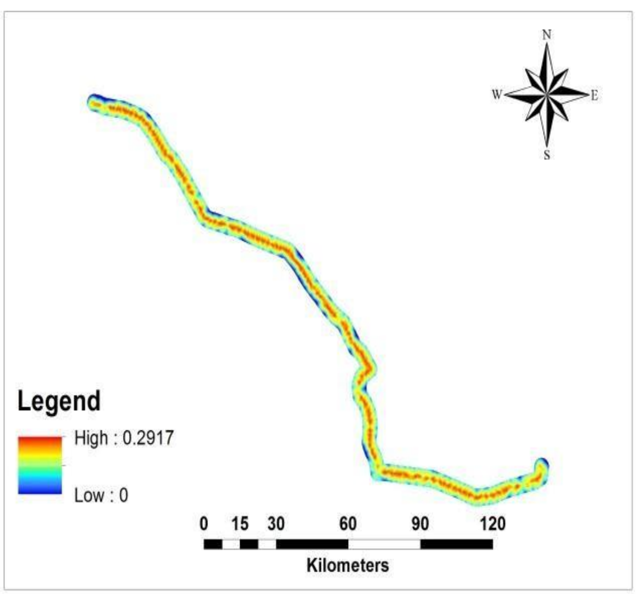
Figure 2. Human activity criterion maps: a) Raw data, b) Standardized data, and c) Human activity risk.

4.2. Distance from Rivers

Another hazardous criterion that is a real risk to pipelines is the distance from rivers. Rivers not only contribute to higher humidity rates and corrosion, but they also have a direct effect on the pipeline such as damages caused by flooding. Pipelines that cross rivers and streams are more vulnerable to breaks when heavy rain and floods occur. A weight of 29.17% is assigned to this criterion. The distance from the river's criterion map is illustrated in Figure (3).

Figure (3) shows oil pipeline risk as a result of the river network proximity and intersection. The risk map is displayed in Figure (3a) prior to normalization using the Fuzzy approach. This map's values range from 0 to 6769.93. Smaller numbers imply lower risk when it comes to the river network, while larger numbers indicate higher risk. The high values show that the river network surrounding the oil pipeline has a significant influence.

Figure (3b), whose scale is standardized using the Fuzzy approach, is the risk map of the oil pipeline in terms of the influence of river drainage. The range of numbers on the map is between 0 and 1. When it comes to the effects of distance and river intersection, the map's large numbers denote more risk. However, Figure (3c) is the outcome of multiplying the weight of the river network's influence criteria 29.17 by the uniform map of the distance from the river network (Figure 3b) divided by 100.



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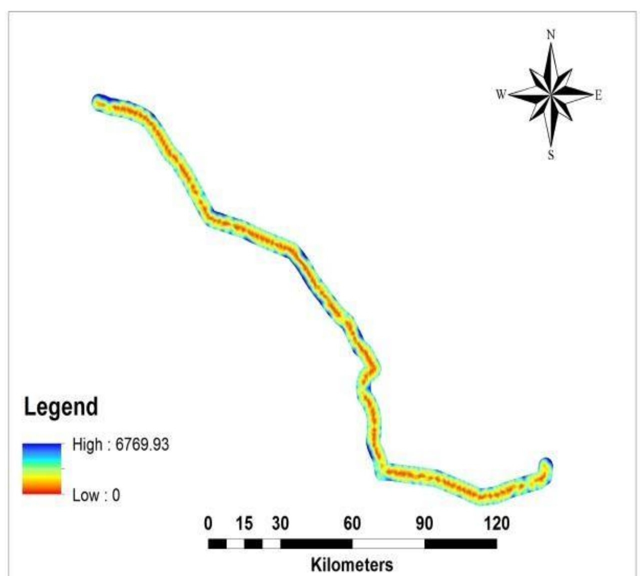

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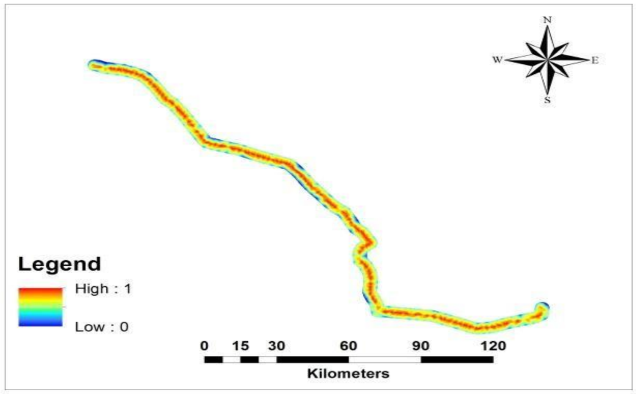

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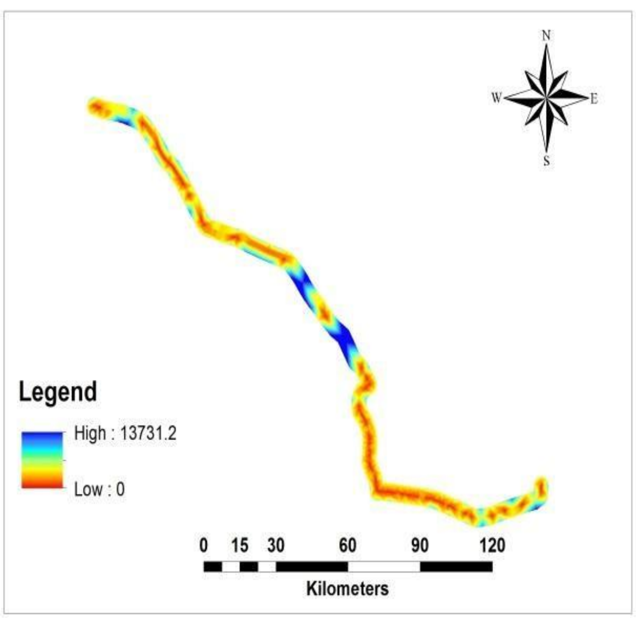
Figure 3. Distance to river criterion maps: a) Raw data, b) Standardized data, and c) Distance to river risk.

4.3. Distance to Roads

This criterion not only shows the risks of having a nearby road to the pipeline but also the effect on human activity near the pipelines as well. All the roads inside the buffer of 3 km were marked and mapped as a potential risk to the pipeline itself (Figure 4). The road risks at two main locations 106 km and 180 km from TTOPCO are the highest. This is because two main roads pass through the pipeline route at these two locations. A weight of 20.8% is given to the distance from the road factor and the map is shown in Figure (4).

4.4. Temperature (Summer)

Elevated ambient temperatures during summer do not reach a level that affects the transported material through the pipeline. However, if the temperature criterion exceeds a certain level negative effects will be inevitable. For this purpose, the risk on the Kurdistan pipeline due to ambient temperature is moderate. This factor has been assigned a weight of 12.5%. Figure (5) illustrates the temperature (summer) map along the pipeline. At some locations certain abnormal, high temperatures on the ranged scale are observed, this is due to the presence of a few oil field flares that raise the scale value.



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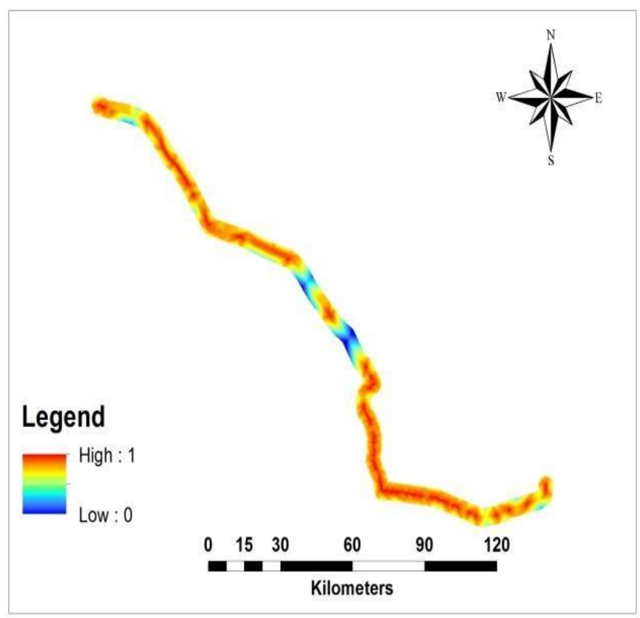

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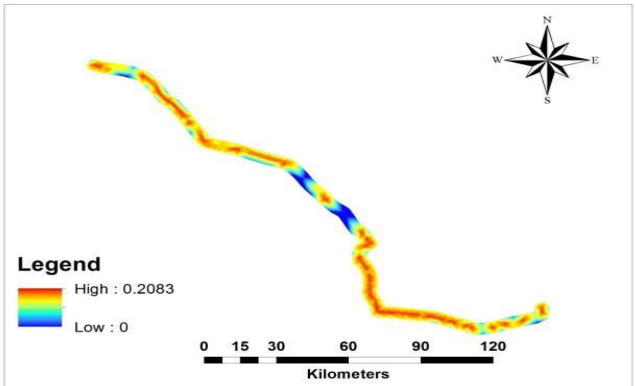

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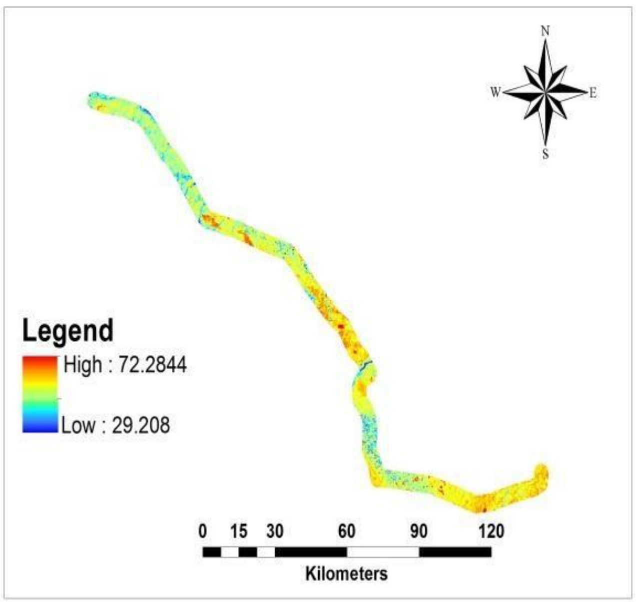
Figure 4. Distance to road criterion maps: a) Raw data, b) Standardized data, and c) Distance to road risk.



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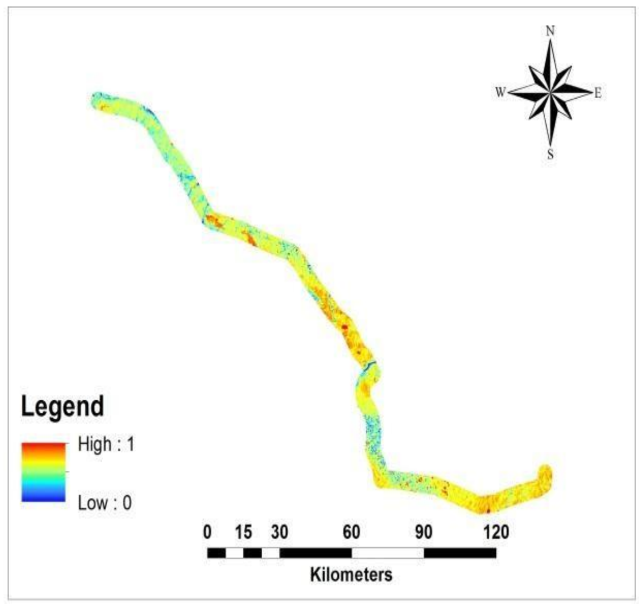

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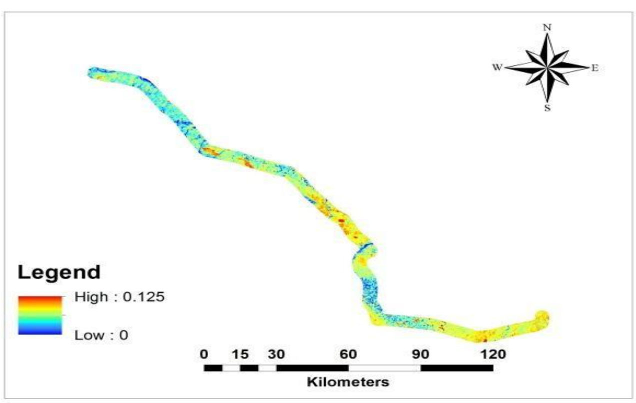

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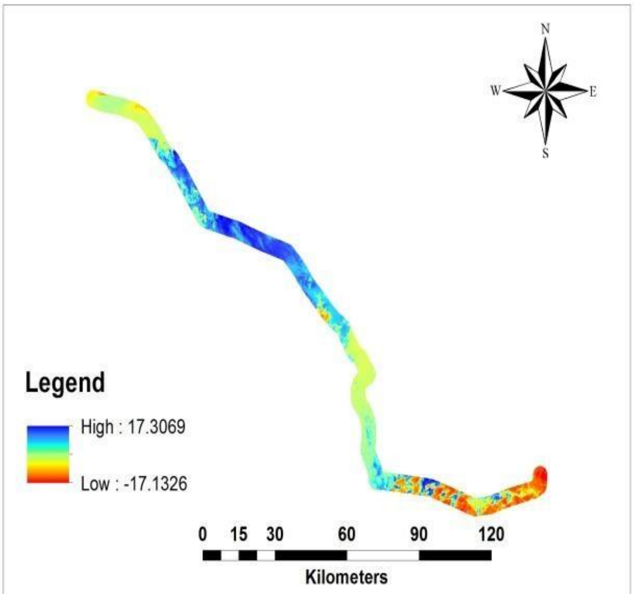
Figure 5. Temperature (summer) criterion maps: a) Raw data, b) Standardized data, and c) Temperature (summer) risk.

4.5. Temperature (Winter)

As negative effects of high temperature, the risk of low temperature should be considered particularly if it drops to a certain level. Clogging and changing the physical properties of the transported oil are a few of those effects. Since the Kurdistan pipeline route does not pass through the high mountain region it does not encounter very low temperatures. That is why winter temperature has been assigned the same weight as summer temperature of 12.5% and they have been merged under a single criterion of Temperature (Figure 6).



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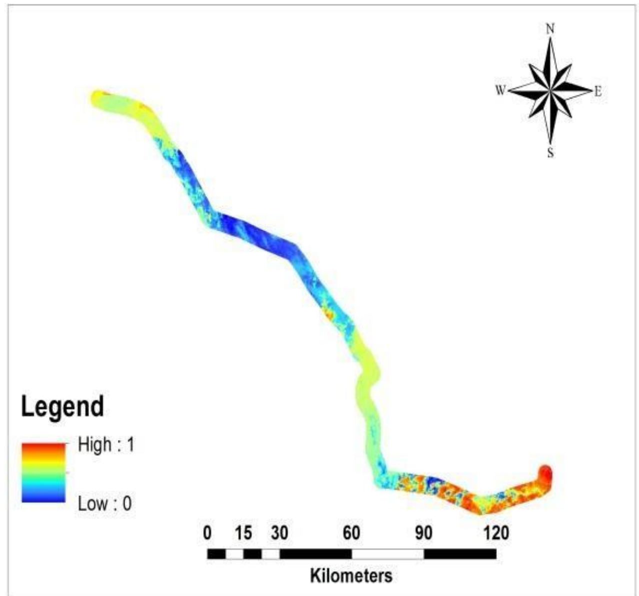

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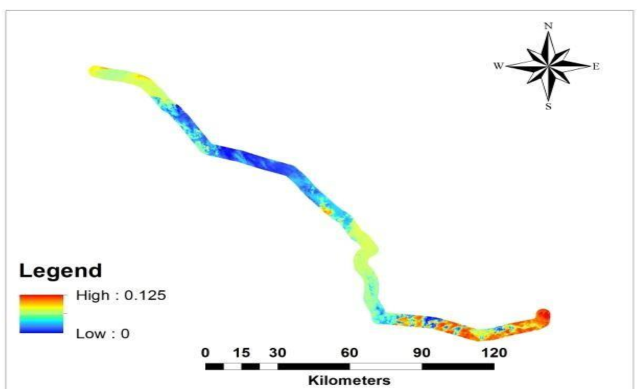
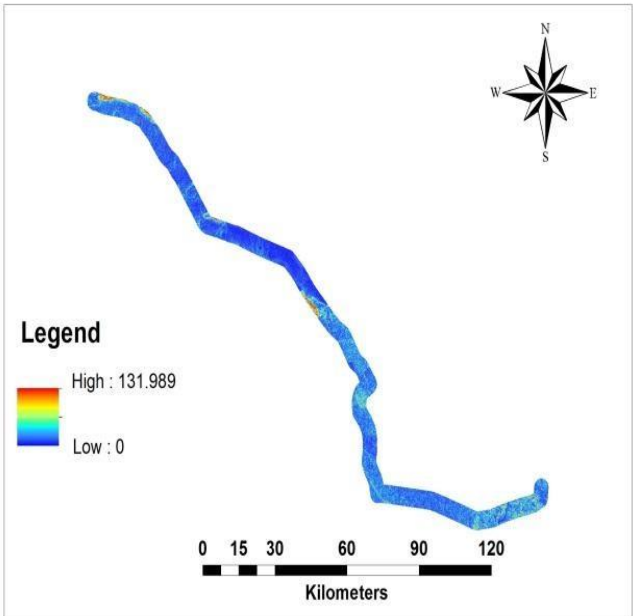


(c)

Figure 6. Temperature (winter) criterion maps: a) Raw data, b) Standardized data, and c) Temperature (winter) risk.

4.6. Appropriate Slope

In the risk assessment of pipelines, the slope is one of the main factors that should be involved. Grading and excavating trenches on steep slopes increase the potential for slips and landslides. Whilst causing erosion which can threaten pipeline safety and increase the risk of environmental impacts. That is why an appropriate slope is seen as an important risk factor considered in the current study. However, after an extensive study and data collection, the results that have been obtained were very little slope along the Kurdistan pipeline. The low slope is due to the topography of the area that the pipeline passes through. For this instance, two sets of risk values were considered, one with a slope as a risk factor with a weight of 12.5% and another without considering slope as a risk factor. Figure (7) shows the map of the Kurdistan pipeline with appropriate slope criterion.



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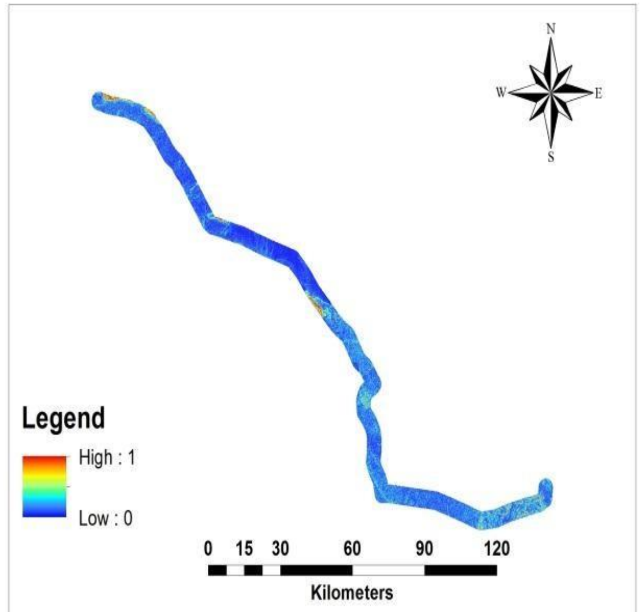

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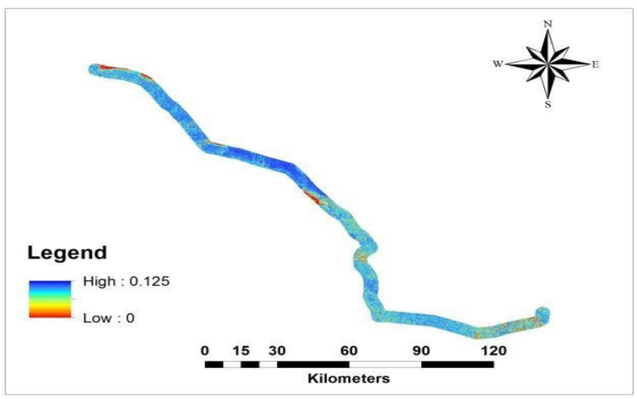

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Figure 7. Appropriate slope criterion maps: a) Raw data, b) Standardized data, and c) Slope risk.

4.7. Criteria Weighting

Generating maps and standardizing values according to Fuzzy logic are not enough to assess the risks of overall all risk factors combined. As explained previously, every project including multi-criterion risk assessment needs prioritize them. Generating an appropriate weight for each of the criteria, a bigger weight for higher risk (Table 1). Then all the raster layers were set to a common scale in a process of standardization by Fuzzy logic, then grades of odd numbers from 1 to 9 are considered, Grade 9 being indicated as the value having the most risk on the pipeline. Whilst the factors with the fewest contribution or least priority risk are being indicated with 1. Similarly, 7, 5, and 3 are for good, medium and low effects respectively.

Since various factors are involved in the process. It is considered different weights to the importance of some factors than others; a nearby village or city possesses twice as much risk as having abnormal temperatures on the pipeline. Hence, all the factors in the current study were weighted to prioritize them. This will help to determine the amount of hazard that each of the factors has on the assessing risks process. Each variable was assigned a weight on a scale of 0 to 1 based on their risk on the pipeline. A weight of 37.50% is given to the factor of human activities, whilst 12.50% weight is given to the factor of temperature as shown in Table (1). Pixel size of 28 x 28 m^2/pixel was chosen due to availability and cost issues.

Table 1. Criteria for risk assessment.

No.	Criterion (Factors)	Weight (%)
1	Human Activity	37.50
2	Distance from River	29.17
3	Distance from Road	20.83
4	Temperature (winter)	12.50
5	Temperature (summer)	12.50
6	Appropriate Slope	12.50

4.8. Overlaying Risk Factor

In raster-based, multi-criterion risk assessment weighting and standardizing the values to a common scale are important steps. These steps convert the prepared data to a format that would be overlayed for further assessment. These assessments will be done by overlaying all the individual prepared layers into a single layer. Then the maximum risk value will be determined based on the combination of the individual maps and overlapping risks at different locations across the route of the pipeline. In the current study Fuzzy overlay is used, as it offers different approaches to calculation. The overlaying risk approach uses the maximum value from all of the input evidence rasters. All the individual criterion maps were combined to form the overlay map (Figure 8). This overlay map uses all the risk factors having a max value of the combined risk of 37.50%.

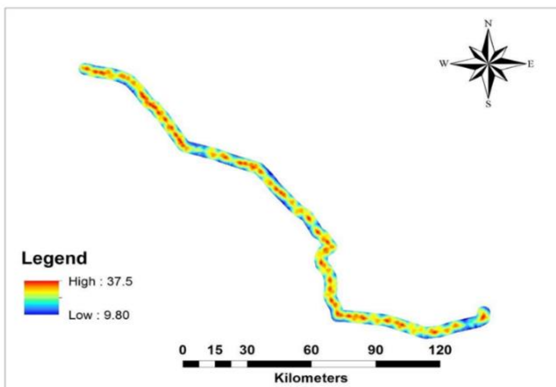

Figure 8. Kurdistan Oil Pipeline Risk Assessment Map.

5. Conclusion

Oil pipelines are exposed to a wide range of threats, often complex. The main issue is that these threats vary in place as well as over time. Long linear assets such as interstate pipelines are particularly subject to different conditions. Some threats can be described as time-dependent and shown as such, while others are more difficult to quantify in terms of their likelihood and/or impact over time. The results of this study show that in order to check the risk of oil transmission lines, the effective use of GIS is very necessary because of its great ability to quantify the threats as much as possible. Because GIS and spatial databases are increasingly used in a wide range of risk analyses. These include the assessment of threats such as land hazards (landslides, earthquake hazards, floods, etc.).

This study was carried out to define and assess risk factors attacking the Kurdistan pipeline route 270 km from TTOPCO to Peshkhabur Using GIS and ArcMap. The major risks that may attack the pipeline are pointed out as human activities, distance to roads and rivers, temperature, and slope. Maps layer for every criterion created. A pipeline risk assessment map is developed and presented. Appropriate Slope Factor contributed a low degree of risk to a level that it could be neglected as a criterion, whilst the human activities contributed with the largest level of risk factor and cause serious hazards. It is concluded that any design of pipeline route and implementation should consider the criteria used in this study. This will reduce the risk level. In addition, continuous monitoring the pipeline during the operation by using GIS lays the ability to integrate different types of spatial data using explicit spatial location.

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