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Using Environmental Sensitivity Index (ESI) to Assess and Manage Environmental Risks of Pipelines in GIS Environment: A Case Study of a Near Coastline and Fragile Ecosystem Located Pipeline

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Abstract**—**Having a very many number of pipelines all over the country, Iran is one of the countries consists of various ecosystems with variable degrees of fragility and robusticity as well as geographical conditions. This study presents a state-of-the-art method to estimate environmental risks of pipelines by recommending rational equations including FES, URAS, SRS, RRS, DRS, LURS and IRS as well as FRS to calculate the risks. This study was carried out by a relative semi-quantitative approach based on land uses and HVAs (High-Value Areas). GIS as a tool was used to create proper maps regarding the environmental risks, land uses and distances. The main logic for using the formulas was the distance-based approaches and ESI as well as intersections. Summarizing the results of the study, a risk geographical map based on the ESIs and final risk score (FRS) was created. The study results showed that the most sensitive and so of high risk area would be an area comprising of mangrove forests located in the pipeline neighborhood. Also, salty lands were the most robust land use units in the case of pipeline failure circumstances. Besides, using a state-of-the-art method, it showed that mapping the risks of pipelines out with the applied method is of more reliability and convenience as well as relative comprehensiveness in comparison to present non-holistic methods for assessing the environmental risks of pipelines. The focus of the present study is "assessment" than that of "management". It is suggested that new policies are to be implemented to reduce the negative effects of the pipeline that has not yet been constructed completely.

Keywords**—** ERM, ESI, ERA, Pipeline, Assalouyeh

I. INTRODUCTION

THIS paper presents the findings of a research on ESI and ERA for pipelines based on HVAs and fragile ecosystems as well as rational applied environmental parameters.

A. Risk and Environmental Risk Assessment

Risk is the intensity of the consequences of a hazardous material or an activity considering their probability of occurrence. Concept of risk is simply showed in Fig. 1.

Pipeline failures cause severe damages. For example a list of recent accidents in the current decade and only in the U.S. is presented [1]: 2007- New York City steam explosion, (July 18); 2007- Propane pipeline explodes, killing two and injuring five others near Carmichael, AL (November 1), the NTSB determined the probable cause was ERW seam failure. Inadequate education of residents near the pipeline about how to respond to a pipeline accident was also cited as a factor in the deaths; 2008- Natural gas pipeline explodes and catches fire near Hartsville (February 5), TN Believed to have been caused by a tornado hitting the facility; 2009- Natural gas pipeline explodes and catches fire near Rockville (May 5), IN, in Parke County about 24 miles north of Terre haute, IN. PHMSA indicated the possibility of external corrosion in its Corrective Action Order (CAO) to the pipeline company. Pictures have been released around the area showing the damage caused. 49 homes were evacuated in a one-mile area of the explosion. No injuries reported; 2009- Two people hurt when a natural gas pipeline exploded in the Texas Panhandle. The explosion left a hole about 30 yards by 20 yards and close to 15 feet deep. The blast shook homes, melted window blinds and shot flames hundreds of feet into the air. The home nearest the blast about 100 yards away was destroyed (5 November); 2009- A new 42 inch gas transmission pipeline near Philo, Ohio fails on the second day of operation. There was no fire, but evacuations resulted (November 14).

Environmental risk assessment (ERA) involves the examination of risks resulting from natural events (flooding, extreme weather events, etc.), technology, practices, processes, products, agents (chemical, biological, radiological, etc.) and industrial activities that may pose threats to ecosystems, animals and people. Environmental health risk assessment addresses human health concerns and ecological risk assessment addresses environmental media and organisms. ERA is predominantly a scientific activity and

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involves a critical review of available data for the purpose of identifying and possibly quantifying the risks associated with a potential threat [2].

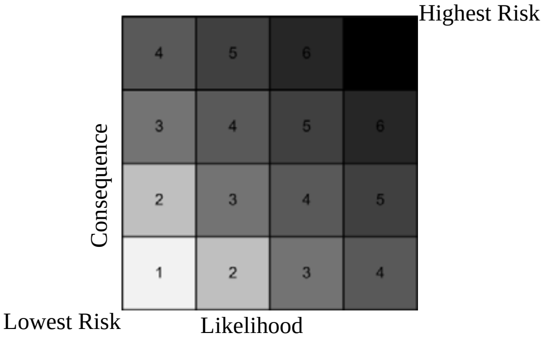

Fig. 1 Simple matrix of consequence (intensity) and likelihood (probability)

B. Environmental Sensitivity Index (ESI)

Environmental Sensitivity Indices (ESI) composed of many field-data are essential for monitoring and control systems [3]. Reference [4] carried out a sensitivity analysis of the Korean composite environmental index (CEI) by examining the CEIs computed by functional forms and those derived from opinion surveys, with a special emphasis on the assessment of weights of environmental indicators and themes: the CEIs are based on environmental themes and pressure indicators.

NOAA's (National Oceanic and Atmospheric Administration) Environmental Sensitivity Index (ESI) approach systematically compiles information in standard formats for coastal shoreline sensitivity, biological resources, and human-use resources. ESI maps are useful for identifying sensitive resources before a spill occurs so that protection priorities can be established and cleanup strategies designed in advance. Using ESIs in spill response reduces environmental consequences of the spill and cleanup efforts [5].

Environmental Sensitivity Index (ESI) maps have been an integral component of oil-spill contingency planning and response since 1979, when the first ESI maps were prepared days in advance of the arrival of the oil slicks from the IXTOC 1 well blowout in the Gulf of Mexico. Since that time, ESI atlases have been prepared for most of the U.S. shoreline, including Alaska and the Great Lakes. Before 1989, traditional sensitivity maps were produced as color paper maps, with limited distribution (because of the cost of reproduction), and without a means for ready updating. However, since 1989, ESI atlases have been generated from digital databases using Geographic Information System (GIS) techniques. As the oil-spill response community moves towards development of automated sensitivity maps, it is important to define what comprises the ESI mapping system and how this information is being developed and distributed using GIS technology [6].

C. ESI in Pipeline Risk Assessment

For the initial phases of risk management, a strict definition of environmentally sensitive areas might not be absolutely necessary. A working definition by which most people would recognize a sensitive area might suffice. Such a working definition would need to address rare plant and animal habitats, fragile ecosystems, impacts on biodiversity, and situations where conditions are predominantly in a natural state, undisturbed by man. To more fully distinguish sensitive areas, the definition should also address the ability of such areas to absorb or recover from contamination episodes [7].

In the United States, a definition for high environmental sensitivity includes intake locations for community water systems, wetlands, riverine or estuarine systems, national and state parks or forests, wilderness and natural areas, wildlife preservation areas and refuges, conservation areas, priority natural heritage areas, wild and scenic rivers, land trust areas designated critical habitat for threatened or endangered species and federal and state lands that are research natural areas [8]. These area labels fit specific definitions in the US, regulatory world. In other countries, similar areas, perhaps labeled differently, will no doubt exist [7], as it so for Iran with more focus on IUCN categories of protected areas.

Shorelines can be especially sensitive to pipeline spills. Specifically for oil spills, a ranking system for impact to shore- line habitats has been developed for estuarian (where river cur- rents meet tidewaters), lacustrine (lake shorelines), and riverian (river banks) regions. Ranking sensitivity is based on the following [9]: Relative exposure to wave, tidal, and river flow energy; Shoreline type (rocky cliffs, beaches, marshes); Substrate type (grain size, mobility, oil penetration, and trafficability); Biological productivity and sensitivity and the physical and biological characteristics of the shoreline environment, not just the substrate properties, are ideally used to gauge sensitivity.

As an example of an assessment approach, an evaluation of a gasoline pipeline in the United Kingdom identified, weighted, and scored several critical factors for each pipeline segment. The environmental rating factors that were part of the risk assessment included [7]: Land cover type; Distance to nearest permanent surface water; Required surface water quality to sustain current land use; Conservation value; Habitat preserves; Habitats with longer lived biota (woods, vineyards, orchards, gardens); Slope; Groundwater; Rock type and likelihood of aquifer; Permeability and depth to bedrock as well as distance to groundwater extraction points. This assessment included consideration of costs and difficulties associated with responding to a leak event. Points were assigned for each characteristic and then grouped into qualitative descriptors (low, moderate, high, very high) [10].

For both gas and liquid pipelines, some areas adjacent to a pipeline can be identified as "high-value" areas. A *high-value area* (HVA) can be loosely defined as a location that would suffer unusually high damages or generate exceptional consequences for the pipeline owner in the event of a pipeline failure. In making this distinction, pipeline sections traversing or other-wise potentially exposing these areas to damage should be scored as more consequential pipeline sections. HVAs might also bring an associated higher possibility of significant legal costs and compensations to damaged parties. Characteristics that may justify the high value definition

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include the following [7]: *Higher property values, Areas that are more difficult to remediate, Structures or facilities that are more difficult to replace, Historical areas, High-use areas.* Identification and scoring of HVAs can be done by determining the most consequential conditions that exist and scoring according to a relative scale first introduced by Muhlbauer. Note that the probability of a leak, fire, and explosion is not evaluated here–only potential consequences should such an event occur. Interpolations between the classifications should be done. A classifications use qualitative descriptions of HVA's and environmental sensitivities to score potential receptor damages has been introduced by Muhlbauer as follows: Neutral (default) =0: *No extraordinary environmental or high-value* considerations; Higher = 0.1-0.6: *Some environmental sensitivity;* Extreme = 0.7-1.0. Another sample of scoring HVAs has been proposed by Muhlbauer. In this scheme, various high-value areas are "valued" on a 0- to 5-point scale with higher points representing more consequential or vulnerable receptors. Attempts to gauge all property values and land uses along the pipeline may not be a worthwhile effort, especially since such evaluations must be constantly updated. The HVA designation can be reserved for extraordinary situations [7].

Presented a study on sensitivity analysis, [11] carried out a numerical sensitivity analysis of the site effect on dynamic response of pipelines embedded in some idealized soil deposits resting on a half space covering a wide range of soil profiles encountered in practice and subjected to vertically propagating shear waves.

A paper described how HSE has piloted a Geographic Information System (GIS) by [12]. To support the expert decision making process and to assist in ensuring consistent responses within statutory deadlines. It considers both the advantages and disadvantages of a GIS over more conventional methods as well as potential developments such as the use of population data in considering societal risks, biological constraints and 3D terrain mapping.

Reference [3] presented an algorithm which emulates human expert-decisions on the classification of sensitivity classes. This will permit the necessary regular updates of ESI-determination when new field data become available using automated classifications procedures.

D. Equivalencies of Receptors

A difficulty in all risk assessments is the determination of a damage state on which to base frequency-of-occurrence estimates. This is further complicated by the normal presence of several types of receptors, each with different vulnerabilities to a threat such as thermal radiation or contamination. The overall difficulty is sometimes addressed by running several risk assessments in parallel, each corresponding to a certain receptor or receptor-damage state. In this approach, separate risk values would be generated for, as an example, fatalities, injuries, groundwater contamination, property damage values, etc. The advantage of this approach is in estimating absolute risk values. The disadvantage is the additional complexity in modeling and subsequent decision making [7].

Another approach is to let any special vulnerability of any threatened receptor govern the risk assessment. There is a protocol [7] for grouping various receptor impacts into three sensitivity areas: normal, sensitive, and hypersensitive. This was developed to perform an environmental assessment (EA) of a proposed gasoline pipeline. Under this categorization, an area was judged to be sensitive or hypersensitive if any one of the receptors is defined to be sensitive or hypersensitive. This conservatively uses the worst case element, but does not consider cumulative effects–when multiple sensitive or hypersensitive elements are present [7]. A third option in combining various receptor types into a risk assessment is to establish equivalencies among the receptors [7]: This approach might be more controversial because judgments are made that directly value certain types of receptor damages more than others. Note, however, that the other approaches are also faced with such judgments although they might be pushed to the decision phase rather than the assessment phase of risk management. This approach presents another possible scoring scheme for some environmental issues and HVAs. In this scheme, the higher scores represent higher consequences. This establishes some equivalencies among various environmental and other receptors, including population density mentioned as a table. These equivalencies may not be appropriate in all cases. This table has been designed to be used with a 4-point population density classification (the 4 classes defined by DOT). It proposes a 1-to 5-point scale to include scores not only for population density, but also for environmental sensitivity and high value areas (HVAs). Scores are determined based on qualitative descriptions and are to be added to the population class number. The worst case (highest number) in each column should govern. When conditions from both columns coexist, both scores can be added to the population class number.

E. Environmental Risk Management (ERM)

Once a risk assessment has been completed and the results analyzed, the natural next step is risk management: [7] "What, if anything, should be done about this risk picture that has now been painted?"

Risk management implies the need for judgment of risk levels, perhaps by the establishment of "acceptable" or "tolerable" risk levels. This is an enormously complex issue [7].

The most common applications of a pipeline risk management program typically include the following [7]: 1. Identification of risks, 2. Reduction of risks, 3. Reduction of liability, 4. Resource allocations, 5. Project approvals, 6. Budget setting, 7. Due diligence and 8. Risk communications. The risk results can also be used to support specific tasks in risk management, including [7]: 1. Design an operating discipline, 2. Assist in route selection, 3. Optimize spending, 4. Strengthen project evaluation, 5. Determine project prioritization, 6. Determine resource allocation, 7. Ensure regulatory compliance, and so on. The present study is not to focus on detailed procedure of risk management but to propose as a recommendation to be carried out.

II. MATERIALS AND METHODS

A. Study Area

Being located beside the Kangan city, the capital of Assalouyeh main city, represented in Fig. 2), the Assalouyeh-Bandarabbas gas pipeline project is to be routed through the mentioned city and be continued along about 385km. The pipeline is to carrying natural gas with 36 inches of diameter (Fig. 3). The case study is the first 29.872km of the project. The study area selected is located along a national park called Naayband (Fig. 4), being introduced subsequently. It is worthwhile mentioning that all geographical coordinates for locations are available in the created maps. Topography is loosely constant all over the study area so that it did not affect the method for used for the study area. The study area is partly in coastal zone.

Fig. 2 Kangan city, Iran– the study area is located in

Fig. 3 36 inches Assalouyeh-Bandarabbas gas pipeline project

B. The most high-value area, Naayband National Park

Having a great value of biological, ecological, aesthetic and recreational aspects as well as intact flora and fauna to some extent, Naayband with an area of 476.871km^2 is a marine national park, comprising a great number of fragile ecosystems. It is located in 300km southeast Boushehr Port comprising a part of Persian Gulf. The pipeline is routing along this park (Fig. 4).

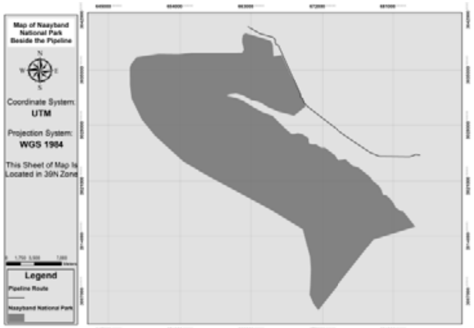

Fig. 4 Naayband National Park beside the selected study area

C. Buffer Zones and Risk Scores (Zone-of influence)

It is important to consider variation over time (temporal variability) and over distance or depth (spatial variability) [13]. In this study due to the short time variations of conditions, temporal variability was forbeared (The pipeline is to carry natural gas within 15-25 years of useful efficiency, however this is generally considered as design index but is not the aim of this study). General worst damage cases have reported a distance of about 500m for direct damages for gas pipeline failures that are even more explosive than that of the other materials [14]. It is essential to determine for the distance a piece of data provide evidence on adjacent lengths of pipe [7]. Considering the probabilities, the distance of the least probable indirect damages to environment, both of natural and built-environment would be 10 times more. So a distance of 5000 m is enough to assume the minimum risk [13]. As the town boundaries are considered as the indirect boundaries of the project, according to the rules of IEPO (Iran's Environmental Protection Organization), in this study a function of exponential scoring to indicate the more sensitivity of less-distant areas to the pipeline route were used. Respectively the two distances of 20m and 5000m were weighted exponentially as the project-active and direct boundaries. Balancing the two available buffer distances, it was concluded that there were necessities in order to determine the sensitivity indices and subsequently risk indices.

D. Equations

Risk assessments generally rely on mathematical environmental fate and transport models and calculate exposure point concentrations in environmental media (e.g., soil, air, water, food), rather than collecting data. This makes sense when using "potential to emit" estimations for proposed facilities [13]. Providing a formula to calculate the index risk scores, some rational formulas were created based on the following logics: 1) Relative risk score ranges would be normally around the relative score of 10 while it is rationally variable. 2) The ecosystems contrary to the human made receptors that can be mobile, are not so. With respect to this, the scores for the ecosystems would be more to a logical amount (e.g. up to 15 than that of 10). 3) The scores should be of the same nature of the other factors so that the final calculations of risk and sensitivity are more reliable and feasible for risk communication. Risk managers use risk estimates, derived through risk assessment, to determine whether a process, activity, or site poses significant risks to human health or the environment. Risk managers may decide, for example, that estimated risks are acceptable, and no action is required, or that risks are too high and require remediation, mitigation, regulation, reduction, or prohibition. Risk managers tend to be non-scientists and may view risk estimates as indicators of "real risks," rather than mere estimates of risk. Risk managers should understand that risk estimates are one component in a multi-faceted decision making process [13]. 4) An exponential relation exists between the distance of pipeline to the fragile ecosystems–the more less-distant, the more score of risk and subsequently the more sensitivity [15]. 5) The areal extent of the assessment must be defined. For example, is an off-site area included in the assessment, and to what distance off-site [13]? Assuming a distance of 5000m as the minimum risk, the minimum risk score for every index and sub-index would be provided so that distances more than 5000m were not considered. 6) A 20m distance for project-active buffer zone as the maximum risk. 7) In distance-based formulas, the D refers to the least distance (LD) between two features. 8) However it may be inferred that such equations are to some extent inconvenient to interpret, but to all of that, because all final scores of sub-indices are multiplied by each other ([7], [13]), such amounts are absolutely rational.

It is worthwhile mentioning that such equations are not available in the reference sources such as EPA guidelines or the like, directly and explicitly.

E. Fragile Ecosystem Score (FES)

Fragile ecosystem is an ecosystem that the involving processes as well as its structure can be disturbed or degraded sensitively so that its functions would finally endangered. For instance in Iran, like most countries abide by IUCN categories for protected areas, national parks are set within the most fragile ecosystems in toto.

The term fragile ecosystem has been used since a relative long time as [16] has ascribed the term fragile ecosystems to the areas that their equilibrium appears to be easily upset and because they become ecologically degraded if certain forms of land use, are practised in them.

Considering the above mentioned framework, formula 1 provides the sample scoring for fragile ecosystems considering their distance. The basic logic of the formula 1 is that supposing a 20m of distance for maximum risk, the relative risk score would be 15 and 1 for approximate minimum risk as well. However the values may be between 0-1 of course in the case of not being farther than 5000m. In this score, relative risk score range (RRSR) is about 1-15 and it is necessary to state that *only* in special situations like FES that there is a RRSR of about 1-15 due to one and a half of relative importance and IRS (explained subsequently) of unlimited rational scores. In other cases RRSR is justified to be set into the range of about 1-10 (Table I).

$$FES = \frac{1}{\sqrt{D}} \times 70 \tag{1}$$

D: (Least) Distance of FES to the pipeline route
RRSR: 0.01-15

Note: The implied range is at least 0.01 and at most 0.5 because of the approximate estimation of the formula. It was recommended to round the score to make the biased bits of scores latent.

In the case of zoning the risk at last, the pipeline was sectioned to 149 sections of equal distances of 200m. Then FESs for the 150 points surrounding the sections were calculated (Table I). The national park was divided into 2260 polygons of 200m×200m to the least distance (nearest distances) to the 150 selected points on the pipeline route. The results are not completely reported here due to brevity and only the most notable results are reported–however it is obvious that all the results have been used in assessing the risk scores. Polygons 1765 and 1440 (FIDs) had a risk score of more than 15 that rounded down to 15.

F. Urban and Rural Areas Score (URAS)

Consisting of 2 towns (Assalouyeh and Naayband) and 14 villages (Fig. 5) involving the pipeline routing, provided (Table II) and their distance sensitivity ranking as well, the study area has human health risk so that relative risk estimations were carried out. The more decrease of distance from the pipeline, the more safety and less sensitivity would be present. Assalouyeh has had 31319 persons and Naayband 10450 in 2006-2007. Villages are the only human settlement in the project region. Distances were measured from the center of the villages and because of settlement concentrations within an average of 500m radius of the village center, the risks were allocated to such polygons in final risk score (FSR).

$$URAS = \frac{1}{\sqrt{D}} \times 45 \tag{2}$$

D: (Least) Distance of URAS to the pipeline route; RRSR: 0.01-10

G. Land Uses

In order to characterize the high-value areas and subsequently equivalencies of receptors, land uses currently involving the pipeline route [17], were identified and classified (Table III) as well as scoring the risk of the identified land uses involving the study area (Fig. 5). LURS and DRS for URB land use were not mentioned in these classifications [17] due to comprehensive consideration separately allocated because of human health risk posed by the pipelines as URAS.

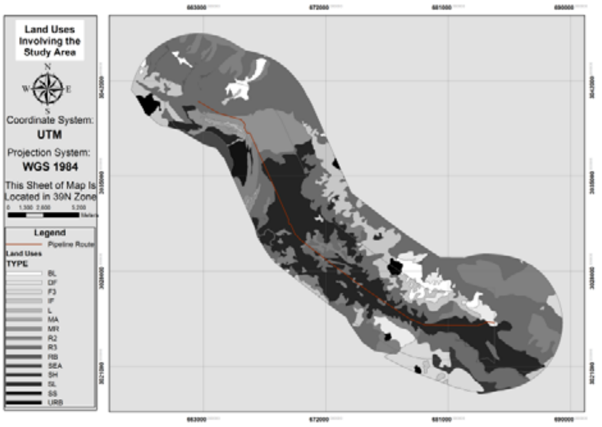

Fig. 5: The identified land uses involving the study area up to 5000m outward the park to and 2500m toward the park (Considering pipeline as an axis)

H. Sensitivity Risk Score (SRS)

A case study categorized oil spill environmental sensitivity was carried out by [18]. The wider Caribbean region, Trinidad that has been classified as a high risk area for oil spills by the Intergovernmental Marine Consultative Organization. In order to develop an oil spill environmental sensitivity index, the intertidal zones of fifteen representative coastal sites were monitored for physical and biological parameters during the dry and wet seasons. On a scale of 1±10, sheltered habitats with high productivity are the most sensitive to spilt oil with an index value of 10. Exposed habitats with low productivity are the least sensitive with a value of 1. The index applied to coastal habitats in Trinidad is as follows: mangrove swamps (10), coral-algal reefs (9), sheltered rocky coasts (8), sheltered tidal flats (7), mixed sand and gravel beaches (6), sheltered fine to medium-grained sand beaches (5), exposed rocky shores (4), exposed tidal flats (3), exposed medium to coarse-grained sand beaches (2) and eroding wave cut platforms (1). This study demonstrates an approach to effectively combine biological and physical parameters into a single environmental sensitivity index to oil spills. Considering the ESI studies regarding to pipeline issues, a study presented an environmental oil spill sensitivity map of Cardoso Island State Park, located in Sao Paulo state, Brazil, including some of its surrounding areas by [19]. This map was designed following the procedures determined by the Brazilian Federal Environment Organ (Ministry of the Environment), which separates coastal habitats in different littoral sensitivity indexes (LSI) to oil spills. Based on the literature review ([7], [19], [13], [15]) and pure knowledge of the ecosystems it is found that the relative sensitivity of the present ecosystems involving the pipeline route can be classified (Table III). It is worthwhile mentioning that due to variety of the ecosystems in toto that is to say the variety of land units, creating mathematical equations for such concepts is to some extent irrational at least by conceptual relationships. From the other side, mathematical equations for the sensitivity of the ecosystems are almost applicable in mapping out the risks.

I. Rareness Risk Score (RRS)

Apart from the sensitivity by itself, in an area with different environmental units it is completely important to consider small-area units [20]. In this direction, a rational score is allocated to every environmental unit based on the distance between them and the pipeline route (Table III).

$$RRS = \frac{1}{2\sqrt{P}} \tag{3}$$

P: Percentage of the land use units from total study area; RRSR: 0.01-2.5

J. Distance Risk Score (DRS)

For calculating the score of distance factor between land uses [17] and the pipeline due to multiple units of land use types, unique polygons were coded as 1-185 so that scoring carried out more reliably (Table IV).

$$DRS = \frac{1}{\sqrt{D}} \times 12 \tag{4}$$

K. Land Use Risk Score (LURS)

The hazard range is defined as the distance from the hazard at which the likelihood of becoming a casualty approaches zero [17]. RRSR for the three previously mentioned scores including SRS, RRS& DRS was 1-2.5, so to keep the relativity, relative scores were multiplied by 4 to keep up with the criterion score of 10. Because of relative balances, it is not proper to score the 3 scores in a range of 1-10 themselves (Table IV).

$$LURS = SRS \times RRS \times DRS \times 4 \tag{5}$$

L. Intersection Risk Score (IRS)

Intersections (I) with environmental elements are of great importance in assessing the risks of pipelines [21]. They are such critical areas that the risk score was calculated as a square relation to provide the IRS in a 200m buffer. For example it is evident that an intersection of 8m across a pipeline, is not two times important than that of 4m but of more importance to a minor extent.

The diameter of the pipe is 36 inches (91.5cm) that is about 1m. Considering an intersection of at least 1m, the minimum risk score would be about 1 (And not 0). IRSs were obtained using the following formula (Table V):

$$IRS = \sqrt{IL} \tag{6}$$

IL: Intersection Length, the length of the pipeline that crosses over a specified land use unit: RRSR: Unlimited

M. Final Risk Score (FRS)

Based on the results, a grid of 200m×200m [22] was created all over the study area, comprising of a total 30914 cells. Then, all risk scores including the following formula were multiplied by each other, implemented to indicate the final risk score (FRS) in a location-based theme. The created grid comprised of a plenty of cells. So addressing all of the cells, the cells were allocated a half score of the minimum score of every RS to make the FRS rational. Fulfilling this assumption, there allocated respectively half minimum scores as 0.23 for IRS, 0.006 for LURS and 0.49 for FES as well as 0.33 for URAS.

The most proper way to measure environmental pressure is based on potential effects of the pressure. In order to determine the relative contribution of the main pressures to each environmental theme, the pressures that have a primary potential effect on each one are selected. Then, each pressure is computed using its relative potential influence, or environmental impact coefficient. By adding all pressures, a sub-index for each environmental theme is, finally, derived as shown in the following formula [4]:

$$\sum_{ijt}^{n} P_{ijt}.E_{ijt} \qquad (7)$$

Where SIjt is a sub-index for theme j in year t, Pijt is pressure i causing theme j in year t, and Eijt is the environmental impact coefficient of pressure I causing theme j in year t. Being guided thorough the mentioned equation and the previously stated logics, all previous calculated cells were converted to raster type (from features) while being of feature (vector) type to be feasible of multiplication in order to calculate final risk scores.

$$FRS = URAS \times FES \times LURS \times IRS \qquad (8)$$

III. Results

The obtained results were summarized in the I-V tables.

TABLE I
SCORING THE FES FOR THE MOST IMPORTANT HVA–NAAYBAND NATIONAL PARK

No.	D	FES	No.	D	FES	No.	D	FES	No.	D	FES
1	893.65	2.34	39	125.86	6.24	77	1898.77	1.61	115	2454.21	1.41
2	850.70	2.40	40	124.46	6.27	78	2098.29	1.53	116	2423.86	1.42
3	799.04	2.48	41	123.07	6.31	79	2297.90	1.46	117	2409.78	1.43
4	747.39	2.56	42	121.67	6.35	80	2497.57	1.40	118	2412.26	1.43
5	699.25	2.65	43	120.28	6.38	81	2697.28	1.35	119	2452.70	1.41
6	652.27	2.74	44	118.88	6.42	82	2897.04	1.30	120	2512.08	1.40
7	605.30	2.85	45	117.48	6.46	83	3096.88	1.26	121	2571.46	1.38
8	558.33	2.96	46	116.09	6.50	84	3141.75	1.25	122	2630.84	1.36
9	511.36	3.10	47	106.97	6.77	85	3174.49	1.24	123	2690.22	1.35
10	491.20	3.16	48	87.85	7.47	86	3142.00	1.25	124	2749.60	1.33
11	491.50	3.16	49	85.95	7.55	87	3055.08	1.27	125	2850.27	1.31
12	491.80	3.16	50	84.05	7.64	88	2979.06	1.28	126	2973.91	1.28
13	492.11	3.16	51	82.16	7.72	89	2914.82	1.30	127	3097.55	1.26
14	493.93	3.15	52	80.26	7.81	90	2863.12	1.31	128	3221.19	1.23
15	500.63	3.13	53	78.36	7.91	91	2826.34	1.32	129	3344.83	1.21
16	509.81	3.10	54	76.46	8.01	92	2803.83	1.32	130	3469.82	1.19
17	524.59	3.06	55	74.57	8.11	93	2795.49	1.32	131	3601.06	1.17
18	577.61	2.91	56	72.67	8.21	94	2798.14	1.32	132	3738.41	1.14
19	558.01	2.96	57	70.77	8.32	95	2803.03	1.32	133	3881.20	1.12
20	542.26	3.01	58	68.87	8.43	96	2807.92	1.32	134	4028.87	1.10
21	485.84	3.18	59	66.97	8.55	97	2812.80	1.32	135	4180.89	1.08
22	407.18	3.47	60	58.41	9.16	98	2817.69	1.32	136	4336.80	1.06
23	431.66	3.37	61	I/ 38.5	15.8	99	2822.58	1.32	137	4496.21	1.04
24	529.57	3.04	62	51.70	9.74	100	2830.17	1.32	138	4624.69	1.03
25	716.00	2.62	63	60.81	8.98	101	2764.11	1.33	139	4749.52	1.02
26	783.93	2.50	64	56.90	9.28	102	2676.04	1.35	140	4876.89	1.00
27	851.86	2.40	65	52.99	9.62	103	2600.40	1.37	141	5009.01	0.99
28	723.32	2.60	66	51.89	9.72	104	2538.30	1.39	142	5145.51	0.98
29	529.32	3.04	67	132.92	6.07	105	2490.75	1.40	143	5286.05	0.96
30	339.98	3.80	68	190.58	5.07	106	2458.61	1.41	144	5442.89	0.95
31	176.05	5.28	69	324.57	3.89	107	2442.47	1.42	145	5632.96	0.93
32	135.63	6.01	70	512.69	3.09	108	2442.65	1.42	146	5804.16	0.92
33	134.23	6.04	71	707.35	2.63	109	2459.15	1.41	147	5997.68	0.90
34	132.84	6.07	72	904.35	2.33	110	2490.37	1.40	148	6169.60	0.89
35	131.44	6.11	73	1102.43	2.11	111	2524.40	1.39	149	6310.73	0.88
36	130.05	6.14	74	1301.09	1.94	112	2558.42	1.38	150	6454.97	0.87
37	128.65	6.17	75	1500.11	1.81	113	2554.38	1.39	-	-	-
38	127.25	6.21	76	1699.36	1.70	114	2500.24	1.40	-	-	

TABLE II
VILLAGES INVOLVING THE PIPELINE AREA AND THEIR DISTANCE SENSITIVITY RANKING AS WELL AS URAS

Rank in LD	Village	LD (m)	URAS	Rank in LD	Village	LD (m)	URAS
1	Bidkhoun	961	1.45	8	Bozbaz	3890	0.72
2	South Sahveh	1446	1.18	9	Khiarou	3891	0.72
3	Khoreh	2201	0.96	10	Bostanou	4250	0.69
4	Marouu	2283	0.94	11	Asgari	4352	0.68
5	Chah Mobarak	2324	0.93	12	Kalaat	4502	0.67
6	North Sahveh	2434	0.91	13	Dehno	4526	0.67
7	Kenar Kheimeh	2639	0.88	14	Akhand	5167	-

TABLE III
SCORING THE RISK OF THE IDENTIFIED LAND USES INVOLVING THE STUDY AREA (SRS& RRS)

No.	Characteristics	Code	Relative Sensitivity Score	SRS	Percent (% P)	Relative Rareness Score	RRS
1	Urban & rural areas & installation (settlement)	URB	URAS	-	0.60	-	-
2	Forest with 5-25 percent canopy cover	F3	6	1.5	6.52	3	0.20
3	Shrub lands with More than 10 percent canopy cover	SH	4	1	0.26	10	0.98
4	Plantation forest	PF	2	0.5	0.21	11	1.09
5	Rangelands with 25-50 percent canopy cover	R2	5	1.25	3.30	6	0.28
6	Rangelands with 5-25 percent canopy cover	R3	1	0.25	56.52	1	0.07
7	Irrigated farming & orchards	IF	8	2	19.09	2	0.11
8	Dry farming	DF	7	1.75	0.28	9	0.94
9	Smooth sand surface lands	SS	1	0.25	0.19	12	1.15
10	Salty lands	SL	1	0.25	3.95	5	0.25
11	Marsh lands with High level surface water	MR	10	2.5	0.69	8	0.60
12	Rangelands with less than 5 percent canopy cover & out crop	BL	3	0.75	6.02	4	0.20
13	Lakes & water reservoirs	L	10	2.5	0.05	14	2.24
14	Large river beds	RB	10	2.5	2.07	7	0.35
15	Mangrove forest	MA	10	2.5	0.07	13	1.89
16	Reed bed in the water swamp margins	RE	9	2.25	0.04	15	2.50
17	Coastal Zone	SEA	9	2.25	-	-	-

5167 IS OUT OF RANGE (>5000M)

TABLE IV
DISTANCE RISK SCORES (DRS) AND LAND USE RISK SCORES (LURS)

NO.	CODE	D.	DRS	LURS	NO.	CODE	D.	DRS	LURS
1	BL	2512.82	0.24	0.14	94	R2	I	I	I
2	BL	4561.03	0.18	0.11	95	R2	530.49	0.52	0.73
3	BL	1317.62	0.33	0.20	96	R2	409.89	0.59	0.83
4	BL	1284.99	0.33	0.20	97	R2	771.48	0.43	0.60
5	BL	1051.17	0.37	0.22	98	R2	233.49	0.79	1.10
6	BL	4861.10	0.17	0.10	99	R2	1864.99	0.28	0.39
7	BL	4647.16	0.18	0.11	100	R2	I	I	I
8	BL	2248.40	0.25	0.15	101	R2	I	I	I
9	BL	2385.71	0.25	0.15	102	R2	1222.04	0.34	0.48
10	BL	1317.62	0.33	0.20	103	R2	89.55	1.27	1.78
11	BL	1284.99	0.33	0.20	104	R3	533.45	0.52	0.04
12	BL	1051.17	0.37	0.22	105	R3	798.86	0.42	0.03
13	DF	1201.60	0.35	0.98	106	R3	1252.19	0.34	0.02
14	DF	3262.35	0.21	1.38	107	R3	2435.96	0.24	0.02
15	DF	2853.61	0.22	1.48	108	R3	2207.78	0.26	0.02
16	DF	1615.81	0.30	1.96	109	R3	I	I	I
17	DF	I	I	I	110	R3	1622.05	0.30	0.02
18	DF	1528.26	0.31	2.02	111	R3	1080.72	0.37	0.03
19	DF	796.46	0.43	2.80	112	R3	I	I	I
20	DF	1615.81	0.30	1.96	113	R3	I	I	I
21	DF	I	I	I	114	R3	776.42	0.43	0.03
22	DF	1528.26	0.31	2.02	115	R3	1252.60	0.34	0.02
23	DF	796.46	0.43	2.80	116	R3	I	I	I
24	F3	1219.06	0.34	0.41	117	R3	1251.83	0.34	0.02
25	F3	4784.74	0.17	0.21	118	R3	4428.05	0.18	0.01
26	F3	2728.41	0.23	0.28	119	R3	3406.21	0.21	0.01
27	F3	4075.98	0.19	0.23	120	R3	1805.68	0.28	0.02
28	F3	1219.06	0.34	0.41	121	R3	1170.77	0.35	0.02
29	IF	2607.83	0.23	0.21	122	R3	2933.68	0.22	0.02
30	IF	3534.44	0.20	0.18	123	R3	456.18	0.56	0.04
31	IF	3992.63	0.19	0.17	124	R3	I	I	I
32	IF	4887.73	0.17	0.15	125	R3	4262.45	0.18	0.01
33	IF	3882.26	0.19	0.17	126	R3	1699.92	0.29	0.02
34	IF	686.30	0.46	0.40	127	R3	1941.10	0.27	0.02
35	IF	4916.03	0.17	0.15	128	R3	798.86	0.42	0.03
36	IF	4420.34	0.18	0.16	129	R3	1252.19	0.34	0.02
37	IF	2713.54	0.23	0.20	130	R3	2435.96	0.24	0.02
38	IF	3466.02	0.20	0.18	131	R3	2207.78	0.26	0.02
39	IF	1285.10	0.33	0.29	132	R3	I	I	I
40	IF	1751.33	0.29	0.25	133	R3	776.42	0.43	0.03
41	IF	1257.20	0.34	0.30	134	R3	I	I	I
42	IF	474.60	0.55	0.48	135	R3	1251.83	0.34	0.02
43	IF	4469.62	0.18	0.16	136	R3	I	I	I
44	IF	1764.75	0.29	0.25	137	R3	I	I	I
45	IF	2248.92	0.25	0.22	138	R3	1622.05	0.30	0.02
46	IF	2114.43	0.26	0.23	139	R3	689.49	0.46	0.03
47	IF	686.30	0.46	0.40	140	R3	I	I	I
48	IF	1285.10	0.33	0.29	141	R3	1252.60	0.34	0.02
49	IF	1751.33	0.29	0.25	142	R3	456.18	0.56	0.04
50	IF	1257.20	0.34	0.30	143	RB	754.63	0.44	1.53
51	IF	474.60	0.55	0.48	144	RB	1237.55	0.34	1.19
52	L	I	I	I	145	RB	2221.47	0.25	0.89
53	MA	259.91	0.74	14.07	146	RB	3164.27	0.21	0.75
54	MA	I	I	I	147	RB	3955.50	0.19	0.67
55	MA	326.56	0.66	12.55	148	RB	3994.28	0.19	0.66
56	MA	1581.84	0.30	5.70	149	RB	3929.05	0.19	0.67
57	MA	1499.92	0.31	5.86	150	RB	1239.35	0.34	1.19
58	MA	1979.75	0.27	5.10	151	RB	807.52	0.42	1.48
59	MA	2492.55	0.24	4.54	152	RB	3666.59	0.20	0.69
60	MA	259.91	0.74	14.07	153	RB	3345.27	0.21	0.73
61	MA	I	I	I	154	RB	1542.60	0.31	1.07
62	MA	326.56	0.66	12.55	155	RB	1015.24	0.38	1.32
63	MR	I	I	I	156	RB	2678.81	0.23	0.81
64	MR	823.74	0.42	2.51	157	RB	1303.74	0.33	1.16
65	MR	I	I	I	158	RB	2119.11	0.26	0.91
66	R2	1061.93	0.37	0.52	159	RB	2221.47	0.25	0.89
67	R2	2176.41	0.26	0.36	160	RB	1239.35	0.34	1.19
68	R2	3028.27	0.22	0.31	161	RB	807.52	0.42	1.48
69	R2	2782.75	0.23	0.32	162	RB	754.63	0.44	1.53
70	R2	2436.16	0.24	0.34	163	RB	1237.55	0.34	1.19
71	R2	799.14	0.42	0.59	164	SEA	1470.74	0.31	0.00
72	R2	I	I	I	165	SH	1532.27	0.31	1.20
73	R2	530.49	0.52	0.73	166	SH	1532.27	0.31	1.20
74	R2	409.89	0.59	0.83	167	SL	4004.01	0.19	0.19
75	R2	1222.04	0.34	0.48	168	SL	2884.99	0.22	0.22
76	R2	771.48	0.43	0.60	169	SL	3311.64	0.21	0.21
77	R2	233.49	0.79	1.10	170	SL	523.67	0.52	0.52
78	R2	89.55	1.27	1.78	171	SL	420.91	0.58	0.58
79	R2	2629.52	0.23	0.33	172	SL	I	I	I
80	R2	2472.16	0.24	0.34	173	SL	I	I	I
81	R2	I	I	I	174	SL	523.67	0.52	0.52
82	R2	1760.03	0.29	0.40	175	SL	420.91	0.58	0.58
83	R2	611.38	0.49	0.68	176	SL	I	I	I
84	R2	213.46	0.82	1.15	177	SS	343.92	0.65	2.98
85	R2	2381.39	0.25	0.34	178	SS	343.92	0.65	2.98
86	R2	1059.05	0.37	0.52	179	URB	3014.05	-	-
87	R2	804.18	0.42	0.59	180	URB	1635.17	-	-
88	R2	I	I	I	181	URB	2783.73	-	-
89	R2	1467.67	0.31	0.44	182	URB	1943.81	-	-
90	R2	1355.57	0.33	0.46	183	URB	4565.39	-	-
91	R2	765.02	0.43	0.61	184	URB	1635.17	-	-
92	R2	1061.93	0.37	0.52	185	URB	1943.81	-	-
93	R2	2436.16	0.24	0.34	-	-	-	-	-

TABLE V
SCORING FOR THE RISK OF INTERSECTIONS BETWEEN LAND USE ENVIRONMENTAL UNIT AND THE PIPELINE (IRS)

LU NO.	IL	IRS	LU NO.	IL	IRS	LU NO.	IL	IRS
17	14.311	3.78	88	10.235	3.20	132	0.899	0.95
21	14.311	3.78	94	14.153	3.76	134	3.684	1.92
52	0.211	0.46	100	16.074	4.01	136	63.514	7.97
54	5.118	2.26	101	3.521	1.88	137	20.257	4.50
61	5.118	2.26	109	20.257	4.50	140	41.419	6.44
63	76.005	8.72	112	0.899	0.95	172	303.045	17.41
65	76.005	8.72	113	14.906	3.86	173	10.549	3.25
72	14.153	3.76	116	3.684	1.92	176	478.796	21.88
81	16.074	4.01	124	63.514	7.97			

The results of FRS calculations showed that a range of 2.231-6.281 out of the range of 0-10 is available in the study area comprising the pipeline route.

Final environmental risk score zoning based on final risk scores for the study area is drawn in Fig 7. As the darkness of the map increases, as showed in the legend, the risk increases subsequently.

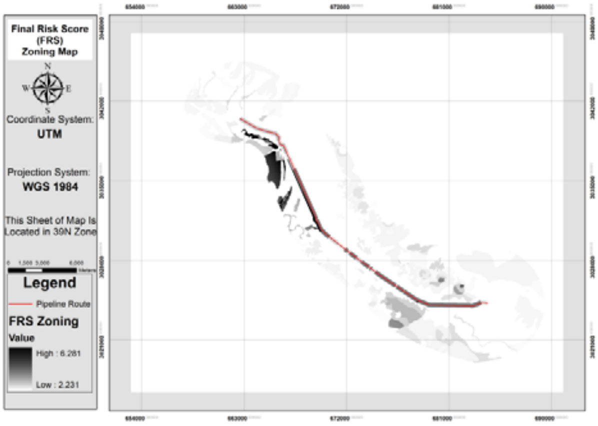

Fig. 7 Final environmental risk score zoning based on final risk scores for the study area

IV. DISCUSSION

One of the reasons that the demand for integrated environmental information has recently increased in many countries is because integrated information is essentially used in evaluating the performance of environmentally sustainable development. As it is very difficult to evaluate the environmental performance on the grounds of so many environmental indicators, the number of indicators should be reduced by aggregating them to a composite environmental index (CEI) to make this information accessible [4]. Addressing this issue, it was tried to get the most out of it, reveal those latent parameters and factors of great concern in assessing the environmental sensitivity as well as the risk estimating that altered to communicate as the following relative and (or even absolute) risk scores: FES, URAS, SRS, RRS, DRS, LURS, IRS& FRS. Having precluded urban and rural areas from LURS, the risk of built-environments was revealed, more than that of including them.

Risk management and risk communications are parts of risk process that are indeed the fundamental of success in an integrated risk assessment as [13] have stated as well. This issue has been addressed in the present study by considering a final risk score (FSR) zoning map outputted from a raster-based GIS to communicate the risks rationally and precisely as well as accurately.

Reference [20] used five criteria for identifying areas of high-value diversity: species richness, rarity, vulnerability, a combined index of biodiversity, and a Standardized Biodiversity Index that measured all four taxa together. The criteria that were used approximately match the applied criteria by [20] to identify the HVA(s). Reference [14] provided us with a distance of about 500m reported on the worst jet fires by natural gases that made it possible to calculate the zones of influence following our risk communication aim.

Being located in the neighborhood of pipeline beginning section along the approximate length of 3.5 km parallel to about the first 4.2 kilometers, mangrove forests (MA code in Land Uses) cover an area of 6.52 % from the whole involving land uses. They have scored the most of all. Those are fragile ecosystems [18] and to some extent exist in small percentage in toto as well as being located in an average distance of 400m from the pipeline.

However a risk score for an important issue – fragile ecosystems– was considered, nevertheless it was revealed that some parts of the influence zone are more affected because of their nature. For instance, mangroves – as previously mentioned– found out to be of the most sensitivity if such a pipeline starts its operation and would exponentially increase the potential hazards for the surrounding environment due to corrosion index [7] mostly for its nature than that of its location. In the other words, some parts of the FSR zoning map were found indicating low relative risk scores due to their nature as it is obvious all over the study area, except parallel to kilometers of 5-6 that the receptor is a land use unit comprised of salty lands (coded as SL).

Being able to be guided through European legislations and directives, Iran has a similar legislative system. During the last 10 years, Europe has faced several major industrial accidents generated by various causes, e.g.: Enschede 2000 – explosion of firework storage, Toulouse 2001 – explosion of ammonium nitrate and Ath 2004 – rupture, explosion, and fire of a gas pipeline. These incidents caused a lot of casualties and major damage to the environment, forced international authorities to examine these phenomena, and, moreover, led the European Commission to adopt legislation to prevent such events [23]. Since having a spatial risk zoning map seems inevitable to manage the risk of pipelines that was considered chiefly here. Considering [7], the applicability of this method cannot be addressed in areas such as Naayband National Park neighborhood and Iran totally, which there are absolutely various ecosystems in a few kilometers and more or less homogenous than that of Muhlbauer has proposed. However he has recommended relative risk scorings for three different situations but none of them represent the presence of land uses comprehensively. For instance, as mentioned previously, Muhlbauer has proposed high-value area scoring for pipelines crossing the residential areas while the built-environment is not the whole environment.

It is worthwhile mentioning that being a new concept that here has been used, no integrated approach considering these issues in a holistic final score – at least for the surrounding environment of the pipelines.

V. CONCLUSIONS

The aim of this study was to assess the environmental sensitivity index in order to assess and manage the environmental risks of potentially expected from a pipeline that is to be routed along a fragile ecosystem, Naayband National Park in Iran. Based on the results of the investigations, the following conclusions were drawn:

1. Mangroves have scored the most of all due to their fragility and rareness as well as being located in an average distance of 400m from the pipeline.
2. Salty lands were the most robust land use units in the case of pipeline failure circumstances.
3. The state-of-the-art method used in this study revealed partial deficits in the other pipeline environmental risks assessments.
4. It is suggested that new policies are to be implemented to reduce the negative effects of the mentioned pipeline that has not yet been constructed completely as well as the other similar pipelines.
5. Environmental risk management of this study area, as the rest of the project, would rather be carried out to set a holistic approach to the environmental risk assessment of pipelines rationally.

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