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A Study on the Possible Oil Spill & Gas Leakage Vulnerable Zones of Gujarat State Using GIS Tools

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ABSTRACT

There are many instances of oil spills and gas leakages in India due to accidents within the industry and also during transmission through pipelines. The spills or leakages are likely to occur near the improper joints. Apart from this, there are a number of other reasons. This study is aimed to analyze all the aspects related to possible oil spills and gas leakages with special reference to Gujarat state. The database considered in this study includes communication network (roads / rail), rivers, elevation, pipeline networks, fault zone, earthquake zone, meteorological data etc. In order to analyse these databases, the well known geographical information system software (GIS) has been used and the possible hazardous locations and the vulnerable zones have been identified by considering the datasets with logical queries. The end maps and results provided from the present study are useful to the industry in order to take precautionary steps and remedial measures that are required to tackle the oil spill and gas leakages in an efficient way.

INTRODUCTION

Gujarat state is located in the western part of India and its oil and gas pipeline network is the largest compared to any other state in India. Through this pipeline network 27.3 million cubic feet of gas and 664582 barrels of oil per day is being transported. The oil fields of Cambay region in Gujarat on land and gas from Hazira fields of south offshore Gujarat are some of the major resources. Additionally, the gas from Mumbai offshore and other fields are entering the Gujarat pipeline network from southern part of Gujarat. Management of natural resources of energy sector like oil, gas, solar, wind emphasizes the richness in energy sector of any state. The gas network pipeline supplies the gas not only to industries but also to the individual houses in major cities like Ahmadabad, Gandhinagar, Rajkot etc. The city gas grid network has been initiated recently and gradually will cover all the cities. Although the Gujarat state has not so far encountered any major oil and gas spills, it is important to study the possible vulnerable locations where the gas or oil leakages are more probable. The oil leakages in the past is mainly reported in the off shore Gujarat (Navneet Rai et al., 2001), as shown in Table 1. There are a few stray incidents of gas leakages on land in Gujarat, among which the gas leakages in Karjan and Ankleshwar are prominent.

In view of above, it is necessary to make an assessment of hazardous and vulnerability map related to oil and gas leakages. This attains importance due to more public awareness, agitations and neglected environment problems on the well known oil and gas leakages outside Gujarat. For example, the recent oil leakage in Gulf of Mexico and it's environ effects has shaken the whole world (Nwankwoala et al., 2009). Similarly, the Bhopal gas tragedy is another incident that has killed and made many people permanently blind (Sriramachari, 2001). Bhopal gas tragedy took place in the month of December during 1984, more than 25 years back but it still remains as one of the worst gas accidents in the history of the country. In view of above major accidents, it is necessary to take all the steps required on the safety and security of the people. It is much more important in Indian context as our population density is much higher compared to other countries. Any minor accident may affect large number of people. Our aim in the present study is to identify the areas vulnerable for possible damage to the pipelines and to do risk assessment for the entire state of Gujarat. For this purpose, the

Table – 1. Offshore oil spill history of Gujarat (source: Navneet Rai, J.P. Pandey, K.Joshi, JIRT, 2011)

Aug '70	15,622/FO	NW coast of India (off Kutch)	Greek oil tanker Ampuria
Aug '89	Not estimated	Saurashtra coast, Gujarat	Merchant ship
May'93	90/FO	Bhavnagar, Gujarat	MV Celelia
May '94	Not estimated/FO	360 NM SW of Porbandar	MV Stolidi
Sep '95	Not estimated/FO	Off Dwarka, Gujarat	MC Pearl
Jun '98	20/crude	Off Vadinar, Gujarat	Vadinar, SBM
Jun '98	Not estimated	Off Porbandar, Gujarat	Ocean barge
Jun '98	Not estimated	Off Veraval, Gujarat	Ocean Pacific
Jul '98	15/FO	Mul Dwarka, Gujarat	Pacific Acadian
Jun '01	Not estimated	Vadinar, Gulf of Kachchh	Not Known
Aug '01	Not estimated	SBM Vadinar, Gujarat	Not Known
Oct' 07	13.9/ FO	Off Jakhu, Gujarat	MV Star Leikanger

well known software package namely GIS has been used in our study (Edgar, 2009).

In fig 1, the geological map of Gujarat is presented. On this map, different data sets have been combined and overlaid. Different rock types shown in the map belong to Cretaceous, Tertiary, Jurassic etc. In our study, we have considered 10 different types of databases. They are- administrative boundaries, roads and rail networks, rivers and inland waters, fault lines, land cover and land use, population density, elevation map, oil and gas pipeline network, hazardous zone etc. In the later section detailed description of each data base is discussed and it's importance in the present study are analyzed.

METHODOLOGY

With a view to find out the risk zone for oil and gas pipelines from the above mentioned data sets GIS based assessment has been carried out. The study is divided into two parts. Firstly, the risks involved due to natural hazards and secondly, hazards due to the manmade structures. The risk assessment due to natural hazard is very important for Gujarat as Kutch region towards the northern part has experienced many major earthquakes with a magnitude of 7 and above (Harsh Gupta et al., 2001).

Apart from earthquake zones, the hazards due to cyclones and flood prone areas have also been considered under natural hazards. Accordingly, the factors affecting natural hazards are mainly due to earthquakes and partially also due to cyclone and flood prone zones.

Hazardous zone

For the sake of clarity and simplicity, all the three hazardous zones have been compiled and prepared as a single major hazard prone area following (Lees et al., 1996). This hazard map is divided into four divisions in such a way that number 1 is highly hazardous and number 4 is least hazardous.

Each zone, for example the earthquake zone has four different ranks. Similarly flood zone also has different ranks. The ranking of each hazard zone due to earthquake, cyclone and flood can be seen in fig 2. As per the rank of each hazard zone, all the individual districts got the weightage. All the individual weightage has been summed up to get the total impact of the hazard prone zone. After all, the weightages have been classified in a range and a final rank for the districts is given to identify the major hazard prone zone.

In table 2, all the four ranks that have been assigned based on the weightage are shown. As can be seen, rank 1 falls in only 1 district and rank 3 falls in as many as 11 districts. As an example, Kutch district is prone to two hazardous zones namely the earthquake and the cyclone. Another example is for the district Kheda. Here the earthquake zone rank is

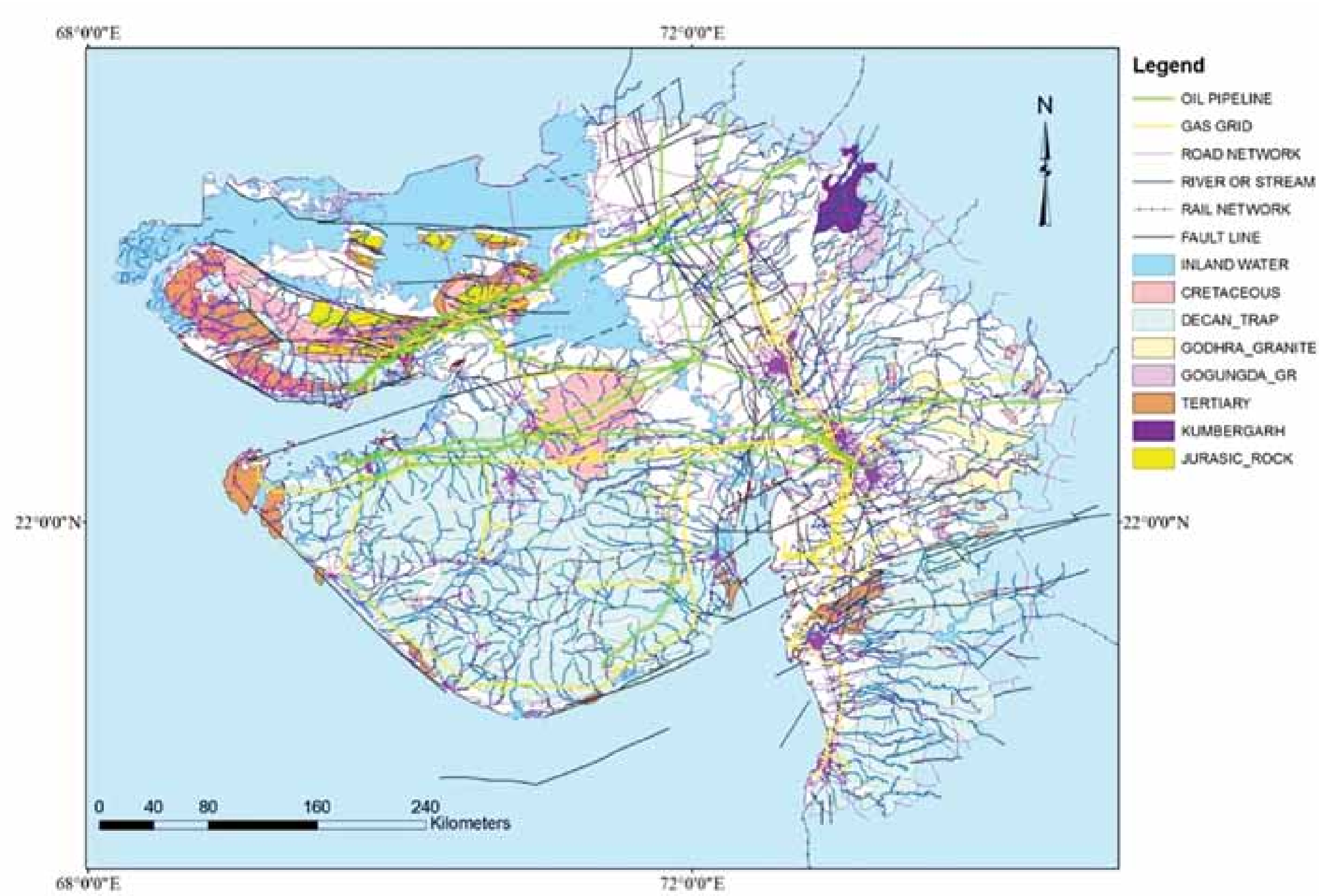

Figure 1. All the spatial databases like road, rail network, streams and rivers, geological units, oil and gas pipeline network etc. has been considered for the analysis problem (source:ISR(www.isr.gujarat.gov.in),GSPL(www.gspcgroup.com),IOCL(www.iocl.com),www.diva-gis.org/gdata) Different colors have been used for different databases.

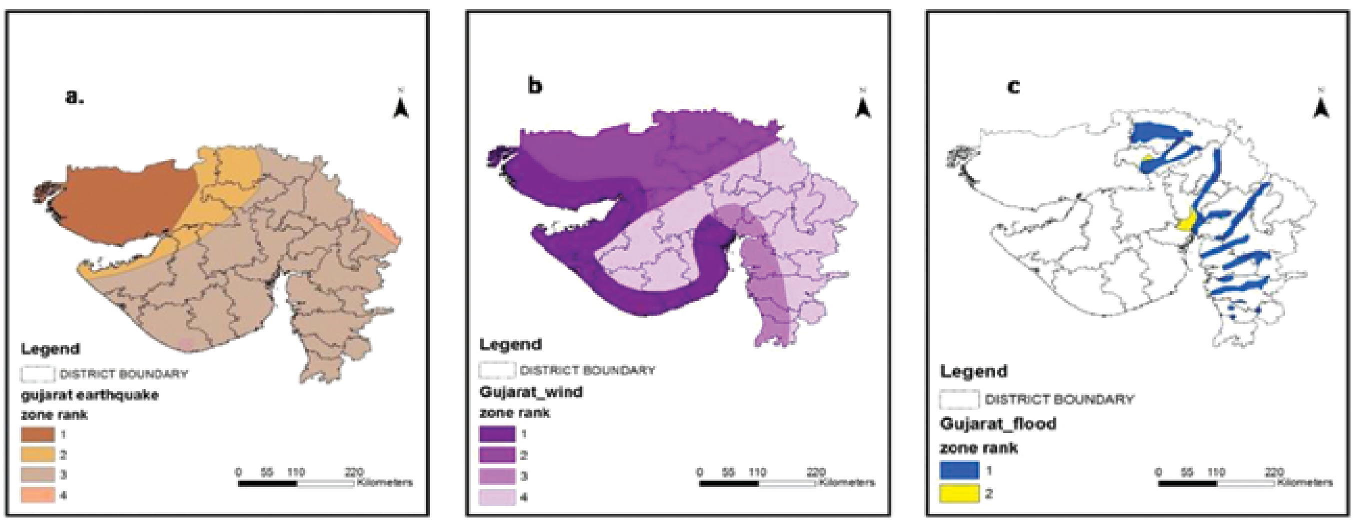

Figure 2. Individual hazard zone map of Gujarat: a. shows earthquake prone zone (source: mapsof.net), b. shows cyclone prone zone (source: adrc.asia) and c. shows flood prone zone. (source: mapsof.net)

Table – 2. Rank wise classification of hazard zones district wise.

No. of Districts	Name of the Districts	Classes of weightage	Rank
1	Kutch	2.00 – 3.75	1
6	Banaskatha, Bhavnagar, Jmnagar, Junagarh, Porebandar, Patan	3.75 – 5.50	2
11	Amreli, Anand, Baruch, Maheshana, Navsari, Rajkot, Sabar kantha, The Dangs, Valsad, Surendranagar, Surat,	5.50 – 7.25	3
7	Ahmedabad, Dahod, Gandhinagar, Kheda, Narmada, Panch Mahals, Vadodara	7.25 – 9.00	4

Table – 3. Area of hazard prone zone, venerable zone due to earthquake damage and Risk zone.

Hazard zones	**Area(sqkm) (approx)** Of hazard prone zone.	%	**Area(sqkm) (approx)** of venerable zone due to earthquake loss	%	**Area(sqkm) (approx)** of Risk zone.	%
1.very high	45652	23.28	45652	23.28	45652	23.28
2.high	51735	26.39	33414	17.04	14125	7.20
3.moderate	64954	33.13	26970	13.75	10489	5.35
4.marginal	33689	17.18	89994	45.90	125764	64.15
total	196030	100.00	196030	100.00	196030	100.00

3 and the flood prone zone rank is 1 and cyclone rank is 4. Thus the total weightage for district Kheda is 8. Following similar procedure all the other districts have got the weightage. In table 2, the number of districts, weightage and the corresponding rank are presented.

In table 3, each rank and the area occupied in terms of percentage as compared to the total area of Gujarat are presented. Hazardous zones have also been classified as very high, high, moderate, marginal etc. based on ranking.

Vulnerable Zone

Vulnerability is a measurement on how the elements at risk in a landscape would be damaged if they experience the same level of hazard (Harsh Gupta et al., 2001). This type of mapping (Fig 3) has been carried out on the basis on loss of property, deaths, injury or damages caused by the impact of the hazard. In Gujarat, the main disaster is possibly due to earthquakes. Major portion of economical loss would be caused by this hazard. Pipelines can thus be affected mainly by earthquakes, rather than cyclone and flood. Accordingly, the vulnerable zoning map depending on earthquake loss is maximum (Eisenberg et al., 1975). Thus, vulnerability is modeled by ranking into 4 classes of zones. Zone 1 being the high rank and zone 4 being the low rank from the vulnerability point of view.

Risk Zonation

After making the hazard prone zone and vulnerable zone, they are combined logically to generate the map of risk zone to do an assessment for pipelines (Muhlbauer, 1999).The resultant map, as before, is reclassified into four zones. Rank 1 is very high risk, Rank 4 is marginal risk as shown in table 3. Additionally, active fault lines and non active fault lines are overlaid on the risk surface to study the vulnerability. In fig 4, the risk zone prepared from the combination of hazard and vulnerable zone is presented (Udoh et al., 2011). High risk zone occupies approximately 23.28% of an area and marginal risk zone occupies 64.15% as shown in table no.3

After the study of hazard, vulnerable and risk zone map, further study has been made considering the active and passive geological faults as discussed earlier. In fig 4, the risk zone is shown along with

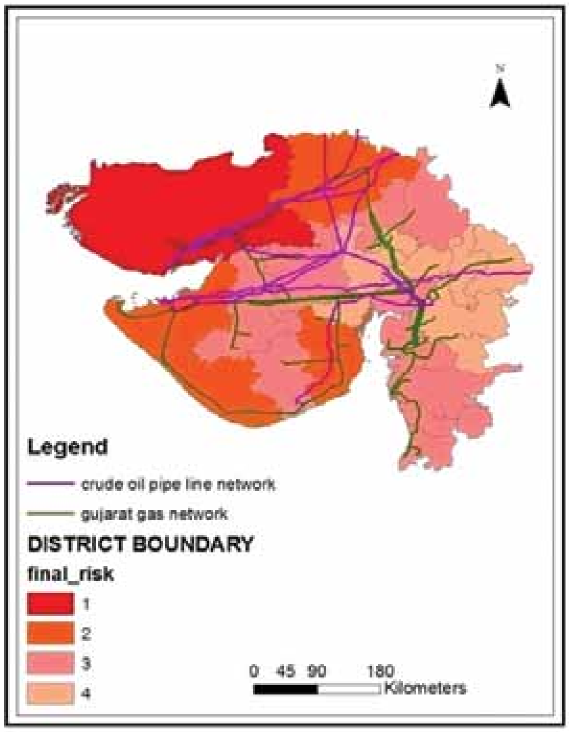

Figure 3. Major hazard prone zone: Based on fig 2 considering 3 parameters namely Earthquakes, Cyclones, Floods, the risk zones have been prepared and shown here in different color -district wise

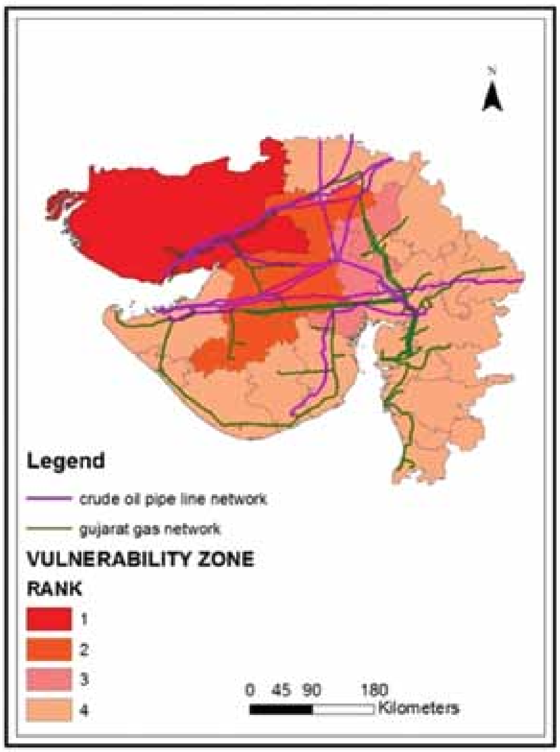

Figure 4. Vulnerable zone based on earthquake damage: From the database earthquake damages occurred in the past and the injuries happened to the personal are known. Accordingly 4 zones have been assigned based on high (rank 1) to low (rank 4).

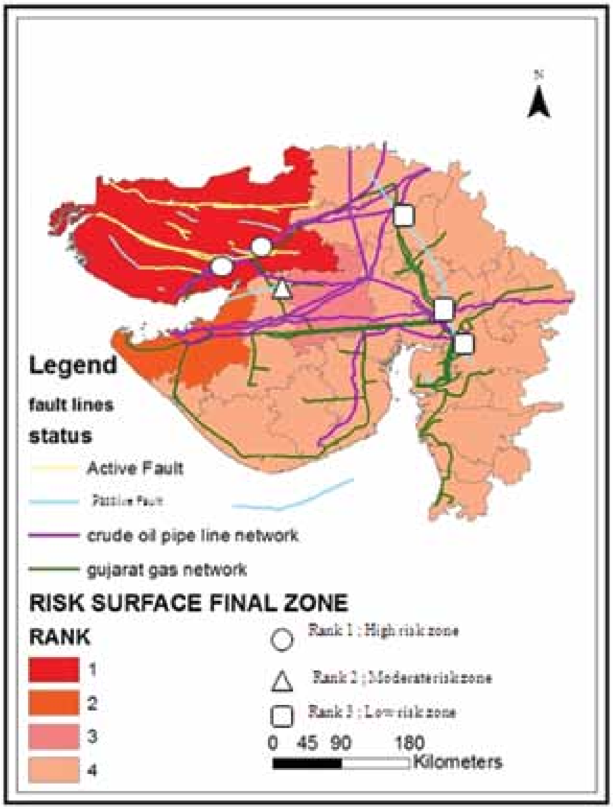

Figure 5. Risk Zone: Based on hazard zone and vulnerable zone due to earthquake damage the natural risk prone zone has been generated. Pipelines passing through risk zone surface, and also active fault lines fall under major risk zone. The high risk locations are shown by different symbols where both the pipelines cross over the active fault line in a high risk area; this location assumed as high risk location and whereas the pipeline fall under moderate zone where the intersection occur with passive fault line and so on.

the active and passive faults, with the oil and gas pipelines overlaid on the map. In order to highlight and pinpoint the locations (a point or a small area) the following analysis has been made. Rank 1 risk zone locations are shown as circles and ranks 2 as triangles etc. as shown in the figure 5. In such an assessment if both the pipelines are crossing the active faults, it is considered here as a very high risk zone. In such an assessment it is assumed that during an earthquake, the ground surface shakes more rapidly near an active fault region as compared to passive fault region. Similarly, it is a moderate risk zone (rank 2) if both pipelines are crossing the passive faults. Rank 3 risk zone location is based on both the pipelines crossing the low risk zone with passive faults. Apart from the above analysis one needs to consider the vulnerable zones based on engineering constructed (man made) structures also as described in the following.

Man made vulnerable zones

It is well known that due to greater demand for the comfort of the people, several man made structures and facilities have been created (Jonkman, 2003). For example, road network, rail network, high raising buildings, transportation of resources, cables and pipes etc. represent man made structures. All the above network with different facilities have been studied systematically in our study and presented in figures 6(A - H). In fig 6A, the road network and gas pipeline network and also the locations of mutual crossing is presented. In fig 6B, the rail network, that crosses the gas pipeline are located. In fig 6C, the rail network and the road network and the locations of crossing the area of gas pipeline network are presented. In fig 6D, the rail network and the oil pipeline network and their crossing locations are presented. In fig 6E, the oil pipeline

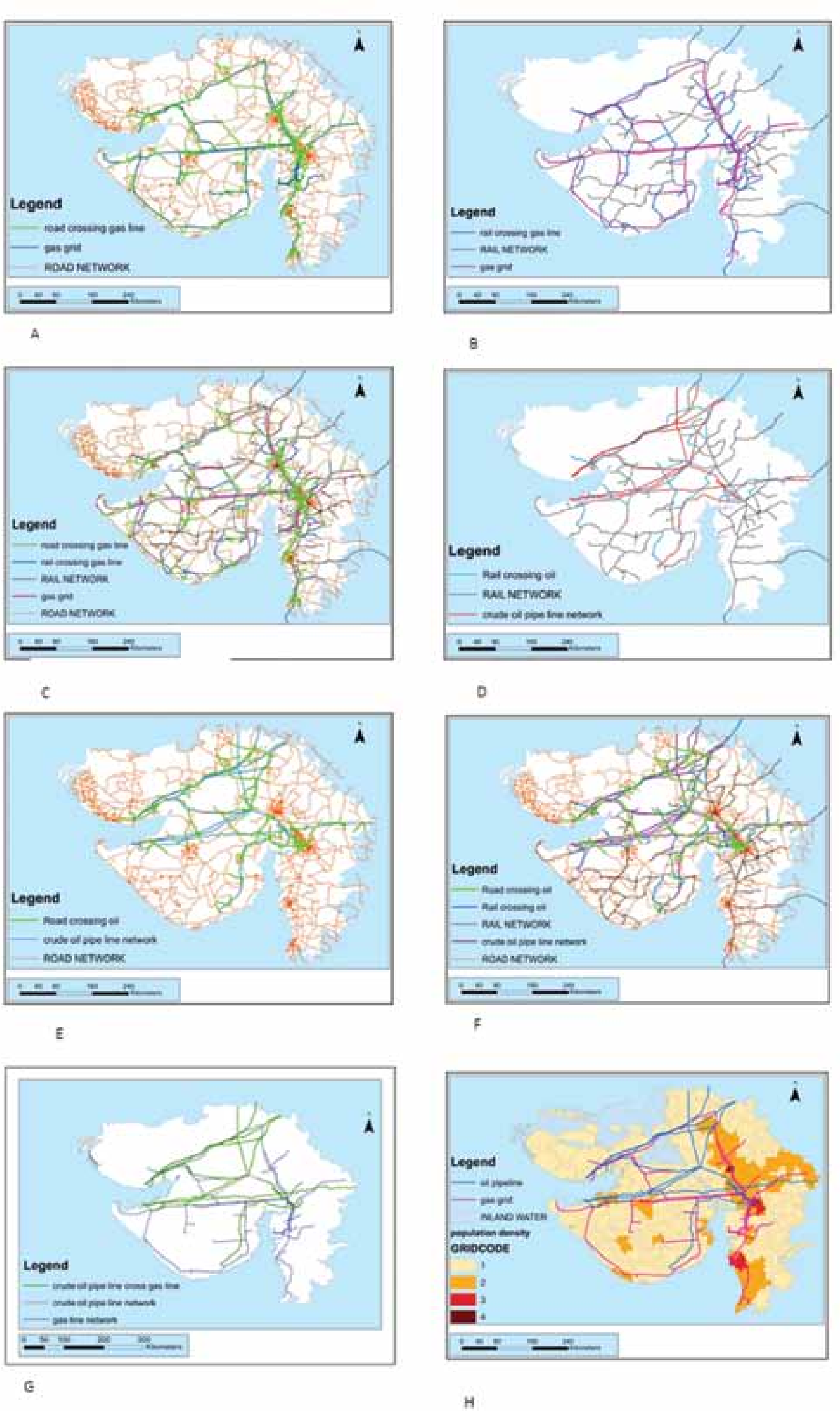

Figure 6. Man made vulnerable zones: A. Gas pipeline crossing road network, B. Gas pipeline crossing rail network, C. Gas pipeline crossing both rail and road network, D. Oil pipeline crossing rail network, E. Oil pipeline crossing road network, F. Oil pipeline crossing both road and rail network, G. Both oil and gas pipeline crossing with each other, H. Population density surrounding pipelines.

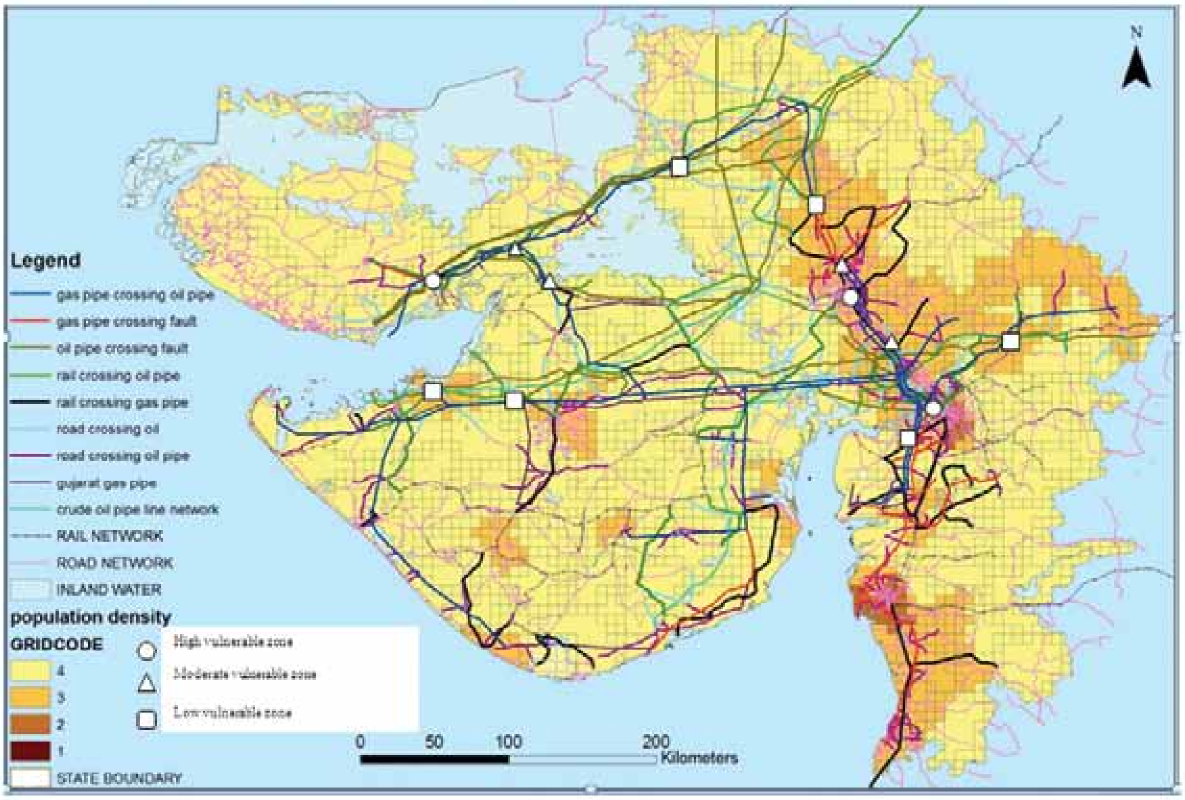

Figure 7. Final man made vulnerable locations: Vulnerability zones based on rail, road network crossing with pipelines, fault lines crossing with pipelines, gas and oil pipeline crossing and population density

and road network and their mutual crossing locations are presented. In fig 6F, the locations of road and rail network that crosses the oil gas pipeline are presented. The locations of gas pipeline network and the oil pipeline network are given in fig 6G. In fig 6H, the population density, inland water locations are presented along with gas and oil pipeline networks. Apart from other parameters, the study of population density as shown in fig 6H attains greater importance as the infrastructure development is increasing fast due to high growth rate of Gujarat state. All these parameters are systematically analyzed in order to identify the approximate locations or small areas and to classify them as highly vulnerable or low vulnerable zones. From the analysis of the risk surface zone, it's easy to find the risk area for the pipelines. Apart from these zones, manmade structures also can cause damage to the pipelines. Such a possibility is discussed in the following.

We have considered different criteria, for example (a) Oil and gas pipelines crossing each other, (b) the road and rail network crossing the pipelines, and (c) populated area with modern infrastructure development etc., (Vincent Tao et al., 2002; NPMS,2003). All these criteria will help in identifying more vulnerable zones for pipeline damage and that they are important zones to examine risk assessment. Accordingly, fig 7 shows the vulnerability zones for both oil and gas pipelines based on all the data. The high vulnerable zone is identified when a gas or oil pipeline crossing a) fault line b) the road c) the rail line and d) the other types of pipelines. Such types of high vulnerable zone can be seen towards south of Kutch, middle part of Gujarat as represented in the form of circles in fig 7. Thus the high vulnerable zone is based on 4 important parameters. Similarly moderate vulnerable locations are also based on 3 or less number of parameters and so on. From the analysis, it is clear that they seem to lie along the north-south trending Cambay lift zone. It is well known that Cambay rift consists of several active and passive faults.

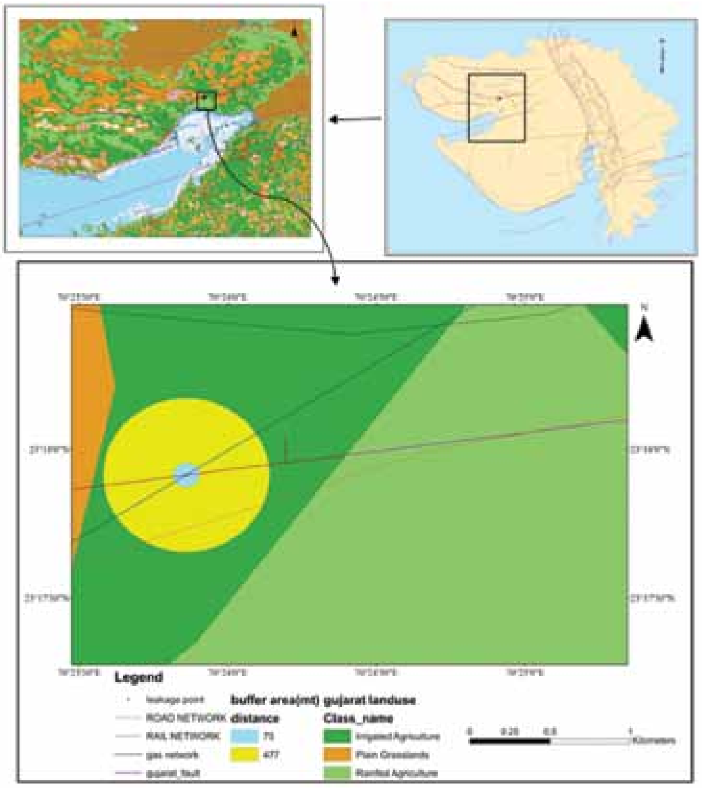

Figure 8. HCA and Fire hazard model: Blue circle showing crucial area after immediate pipe burst (HCA) and yellow circle shows increasing heat radius for continuous gas flow.

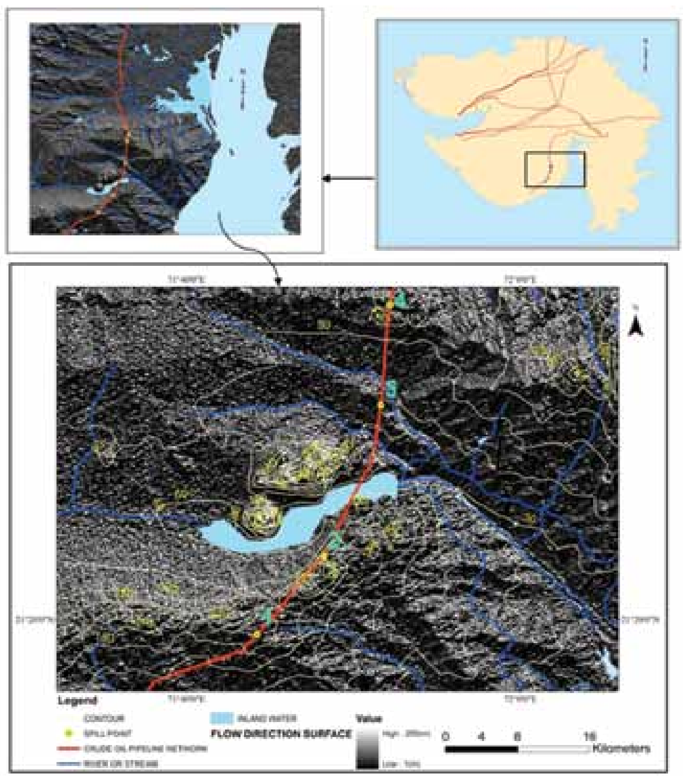

Figure 9. Oil flow direction: Oil spread direction showing effected area of South West Gujarat, pipeline passing through undulating elevated surface created from raster elevation. It helps to visualize the slope direction of oil flow as per gravity

RISK ASSESSMENT

HCA and Fire hazard model

After the identification of vulnerable zones, it is important to study the assessments of risks involved due to leakages of oil and gas (Han et al., 2010). In risk assessment, the parameters required are the radius from the gas leakage area. This is important in order to undertake the measurements to protect the people from their safety, the proximity of the leakage locations (Mark, 2000). For this purpose one can compute the radius from the gas leak locations to identify the high consequence area (HCA) using the following formula;

$r = 0.685 * \sqrt{pd^2}$
r = radius of impact area
p= maximum pressure (psi)
d= pipe diameter (in)

If the gas leakage could not be stopped over a sufficiently long period, the high consequence area is also vulnerable to thermal radiation producing anomalous heat surrounding the leakage location. Such increase in heat may sometime leads to jet fires that may cause a major hazard to the human settlements and properties. Thus it is important to know the amount of heat flux that can be generated from the leakage location. The required equation to compute the heat flux is: (Bilo et al., 1997; Hymes, 1983; Staff Report, 2001).

$$Ii = n\ Xg\ Qeff\ Hc\ /\ 4np\ \pi\ x^2i$$

Where,
I_i = heat flux
Hc = heat of combustion (constant for given product). 50,000 kJ/kg for methane;
n = combustion efficiency factor = 0.35
Xg = emissivity factor = 0.2;
n_p = number of point sources;
Q_{eff} = effective gas release rate;
x_i = radial distance from heat source *i* to the location of interest.

For the above heat flux, it is also important to know the extent of the area of anomalous heat generation. The areas radius can be computed using the following formula;

$$r = \sqrt{2348pd^2/Ii}\ (ft)$$

Where,
r = radius of the affected area from the source leakage location
Ii = threshold heat intensity (Btu/hr/ft)
P = line pressure (psi)
d = pipe diameter (in)

As an example, by assuming the gas leakage close to Bachao village near little Rann of Kutch, a high consequence area (HCA) and fire hazard model has been computed and presented in fig 8. In this model, we assumed 18 inch diameter for the gas pipeline with 400psi pressure inside the pipeline. From our study, 75 square meter of an area is likely to be affected as a high consequence area and as much as about 500 meters radius will be affected as a fire hazard zone. This information is very useful for the gas pipeline industry to undertake various mitigation measures to curtile the gas leakages.

Oil Flow Direction

In another example, we have considered oil pipeline leakage in southern part of Gujarat of Saurashtra region. In fig 9 oil pipeline passing through the area close to the water body is presented. This is the raster map for localized area using terrain elevation data. The yellow color indicates the contour lines of elevation. The blue line indicates possible rivers or stream lines. If there is a leakage of oil at a location '1' the oil is likely to flow towards the south direction. If there is a leakage location of '2' the oil is likely to flow towards the north and may pollute the water body. Similarly, if there is an oil leakage near the location '3', the leakage follows the stream path towards south east direction and may reach the water body too. At location '4' the oil is likely to flow towards the north. Such information obtained from the study will be very helpful to initiate the proper remedial measures in order to minimize the environmental pollution. (Jonkman, 2003; Pandey et al., 2011; Shalaby et al., 2007).

CONCLUSIONS

Destruction of ecosystems both marine and also inland are becoming more common due to increased population, pollution etc. Several accidents are happening in the world during transportation of oil and gas from one location to the other. Bhopal gas tragedy is still a nightmare in India. In order to understand the risks more clearly and to suggest mitigating measures, we have considered here the problem due to oil spills and gas leakages. We have taken up different datasets and many parameters with Gujarat state as an example. It is well known that compared to any other state, Gujarat has developed large infrastructure in terms of pipelines for supplying and also transmitting oil and gas. For this purpose, the popular geographical information system (GIS) software has been used with all types of different datasets that are directly or indirectly related to oil and gas pipeline networks.

Based on the present study, the hazardous locations and vulnerable zones have been identified considering the important data bases like earthquake zone, active faults, rail way network, road network, cris crossing of pipelines etc.

For example high risk zone is marked based on both oil and gas pipeline crossing an active fault line in a high seismicity region and assigned as rank 1. Similarly less ranking based on other parameters. This way high risk zones of rank 1 are located near Gandhidham and Bachao region of Kutch region. Moderate risk zone is observed near Jetpur of Saurasthra region. Similarly, low risk zone can be seen in Palanpur of north Gujarat, Nadiad and Vadodara of South Gujarat as shown in fig 5. This study has also been extended and showed the extent of the area that could have been damaged due to oil spillage and gas leakages. The output of the present study is very much helpful to managers and decision makers to take extra measures at a few specific important locations that are more vulnerable to prevent possible oil or gas leakage. High consequence area and fire hazard model have also been computed by considering the data at two locations to demonstrate the utility for gas leakage. It helps to take the quantum of remedial measures to be taken up in case of any accidents due to breakage in the oil and gas pipelines. Additionally, an attempt has also been made to show the direction of oil flow due to accidents.

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REFERENCES

A Staff Report, 2001. Natural Gas Development Continues To Drive Worldwide Pipeline Construction Activities, Pipeline & Gas Industry, v. 84, no.11.pp:1-25.

Bilo, M and Kinsman, PR, 1997. Thermal Radiation Criteria Used in Pipeline Risk Assessment, Pipes & Pipelines International, November-December, pp: 17-25.

Edgar Fabiàn Lara., 2009. GIS As a Tool To Assess Pipeline Integrity, TGS. www.igu.org/html/wgc2009/papers/docs/wgcFinal00395.pdf

Eisenberg, NA, Lynch, CJ and Breeding, RJ., 1975. Vulnerability Model: A Simulation System for Assessing Damage Resulting from Marine Spill, Environmental Control, Report CG-D-136-75, Rockville, MD, USA.

Han Z. Y. and Weng W. G., 2010. An Integrated Quantitative Risk Analysis Method for Natural Gas Pipeline Network, Journal of Loss Prevention in the Process Industries, Vol. 23, No. 3, pp. 428-436. doi:10.1016/j.jlp.2010.02.003

Harsh Gupta, Harinarayana T, Kousalya M, Mishra DC, Indra Mohan, Purnachandra N Rao, Raju PS, Rastogi BK, Reddy PR and Sarkar D, 2001. Bhuj Earthquake of 26 Januray, Journal of the geological society of India, v.57, pp: 275-278.

Hymes., 1983. The Physiological and Pathological Effects of Thermal Radiation, Systems Reliability Directorate, Report SRD, R275, Culcheth, Warrington, UK.

Jonkman S. N. Van Gelder P.H.A.J.M., Vrijling J.K. ,2003. An Overview of Quantitative Risk Measures for Loss of Life and Economic Damage, Journal of Hazardous Materials, v. 99, no. 1, pp: 1-30.

Lees, FP, 1996. Loss Prevention in the Process Industries: Hazard Identification, Assessment and Control," Second Edition, Vol. 2, Butterworth-Heinemann, A division of Reed Educational and Professional Publishing Ltd, Oxford, UK.

Mark J Stephens, 2000. Topical report A Model for Sizing High Consequence Areas: Associated with Natural Gas Pipelines, Gas Research Institute of Canada.

Muhlbauer W. K., 1999. Pipeline Risk Management

Manual, 2nd Edition, Gulf Professional Publishing, Maryland Heights, pp: 423.

Navneet Rai, Pandey IP and Kamal Joshi, 2011. Impacts and Management of Oil Spill Pollution along the Indian Coastal Areas, Hatam Publishers. J Ind Res Tech., v.1, no. 2, pp:119-126.

NPMS, National Pipeline Mapping System, 2003.web site URL: (http://ops.dot.gov/; http://www.bts.gov/gis/reference /npms-content.html)

Nwankwoala HO and Nwaoug C, 2009.Utilizing the Tool of GIS in Oil Spill Management, Nigeria, Global journal of Environmental Sciences v.8, no.1, pp:19-29

McCay Deborah French, Krause CJ Beegle, Rowe Jill & Rodriguez Wilfrid, 2009. Oil Spill Risk Assessment – Relative Impact Indices by Oil Type and Location, Emergencies Science Division, Environment Canada, pp: 655-681

Shalaby A. and Tateishi R., 2007. Remote Sensing and GIS for Mapping and Monitoring Land Cover and Land-Use Changes in the Northwestern Coastal Zone of Egypt, Applied Geography, v..27, no.1, pp: 28-41. doi:10.1016/j.apgeog.2006.09.004

Sriramachari. S, 2004. The Bhopal gas tragedy: An Environmental Disaster Current Science, v. *86*, no. *7, pp: 905-920*

Udoh JC and Ekanem EM, 2011. GIS based risk assessment of oil spill in the coastal areas of Akwa Ibom State, Nigeria, African Journal of Environmental Science and Technology., v. 5, no.3, pp: 205-211

Vincent Tao C., Yong Hu, 2002. Assessment Of Airborne Lidar and Imagine Technology For Pipeline Mapping and Safety Applications, Pecora 15/Land Satellite Information IV/ISPRS Commission I/FIEOS Conference Proceedings, Canada.