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RISK ASSESSMENT OF PETROLEUM FIRE USING GEO-SPATIAL TECHNIQUES

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ABSTRACT

Required GIS database has been created after collection of data from the various sources. Various thematic layers are created in GIS for the different parameters and phenomenon required to be estimated for the assessment of risk and vulnerability due to petroleum fire in Jaipur City. Available satellite images have been processed digitally in ERDAS Imagine for preparation of land use/ land cover map of the Jaipur City for estimation of built-up areas.Further, analysis has been carried out in GIS i.e., buffering, overlay analysis, raster calculator etc., for estimation of exposure, hazard, vulnerability and risk. Ward wise hazard, exposure, vulnerability and risk maps are generated for the Jaipur City. Further, City has been classified according to risk of petroleum fire risk. Study have successfully demonstrated application of Geo-spatial techniques for vulnerability and risk analysis of Fire Hazard due to petroleum products stored and distributed through various facilities located at different places in the Jaipur City. Such a study will be useful for Municipal Authorities and Govt. Officials to identify high risk areas and accordingly suitable mitigation/adaptation measures can be initiated.

Key word: **-** Risk, Disaster, Petroleum, Hazard and Fire

1.1 Introduction

Risk assessment has received increased attention since the recognition of both the potential threat to human health from hazardous substances and the potential for releases of hazardous substances into the environment (Ferrier N et. al. 2003). India, with its unique geophysical setting and socio-economic conditions is highly vulnerable to natural and manmade disasters due to number of factors, both natural and human induced, including adverse geo-climatic conditions, topographic features, environmental degradation, population growth, urbanization, industrialization, flawed development practices, etc (K.J. AnandhaKumar et. al. 2011).

Urbanization is increasing rapidly in India and shall continue for the next few decades. Urban landscapes changes over time as new urban fabric is added and also as the existing fabric is internally modified (e.g. New buildings replace old ones, plots are amalgamated or subdivided, street layouts are modified) (Knox, 1995; Cadwallader, 1996). These patterns of urban densification and internal modifications are of major concern to sustainable development because they represent the physical manifestations of a range of social, economic, cultural, and political dimensions associated with urban dynamics.

With the advent of rapid urbanization, it has become extremely necessary to study vulnerability assessment of urban areas for different type of natural and manmade disaster like petroleum fire. Disasters related to fire are very critical in urban areas owing to dense population and lots of resources are on stake.

The fire related disasters may occur for different reasons ranging from malfunctioning of an installed mechanical device to mistake committed by any personnel. The consequences of such failure may leads to huge losses of lives, resources and degradation of environment.

1.2 Petroleum Fire

The fire is a major disaster in terms of deaths, injury, loss of business, property and man-days loss, displacement of people and adverse environmental impact. All petroleum products are flammable and vapors may form explosive mixtures at specific concentrations. Even small quantities of petroleum vapor in air can form a flammable mixture, which can be ignited by a flame, hot element, spark or other source of ignition. In the processing and handling of petroleum products that are used in daily life such as LPG, petrol, diesel, there is risk of fire and explosion with danger to life, and adversely affects the environment. Because of the nature of petroleum fires, it can soon be out of control and make it more intensive. Increased use of petroleum day by day increases the necessity of petroleum storage in the metro cites as well as in small cities. Large storage of petroleum products increased the chances of fire accidents at storage locations due to highly flammable characteristics of these products.

1.3 Overview of Present Study

The present study is aimed to assess the potential of petroleum fire hazard in Jaipur city through vulnerability and risk assessment at ward level scale using geospatial analysis techniques like remote sensing and GIS. Various kind of analysis for the assessment such as exposure assessment, hazard assessment and vulnerability assessment are done for the assessment of total fire risk in Jaipur city, the capital of Rajasthan. In the present study, different type of data such as survey of India Toposheet, maps, petroleum storage locations and their capacity of storage, ward wise population, information about critical infrastructure, economical & social as well as the environmental status of the society were used. Above mentioned data was obtained from different organizations and departments of central as well as Rajasthan government.

2. Data and Methodology

2.1 Data

In the present study the Petroleum fire risk assessment of Jaipur city has been done using geospatial analysis techniques like remote sensing and GIS. Different type of spatial and non-spatial data has been collected from diverse sources. Collected data are representing various parameters and phenomenon's required for assessment of petroleum fire vulnerability and risk assessment in GIS. Various thematic layers are created in GIS for the different parameters and phenomenon required to be estimated for the assessment of risk and vulnerability due to petroleum fire, such as Toposheet, maps, petroleum storage locations and their capacity of storage, ward wise population, information about critical infrastructure (i.e. Schools, Hospitals and Commercial Buildings) shown in Figure 2, economic, social (use to calculate social vulnerability) and environmental status of the society.The data that has been used in study is obtained from different Government or Non-Government organizations (i.e. IOCL, BPCL and HPCL) and Departments (I.e. Survey of India, Jaipur Development Authority and Jaipur Nagar Nigam) of Central as well as Rajasthan Government. Detailed information about the data used and their source are as following.

2.1.1 Toposheet and Map

Survey of India Toposheet i.e. 45N09, 45N10, 45N13 and 45N14 at a scale of 1:50000, covering Jaipur city have been collected from Survey of India. Other maps and data of Jaipur city like ward map, municipal boundary map, road network map, population data, location map of petroleum facilities, critical infrastructure etc., have been collected from the Jaipur Municipal Corporation and Jaipur Development Authority. These Maps are pre-processed in ArcGIS to rectify and supply the coordinate and projection information to the maps. Further, these maps are used as base maps for creation of various thematic layers in GIS i.e., ward boundary, road network, railways, critical infrastructure and Petroleum Storage facilities etc.

2.1.2 Census Data

The ward wise of Jaipur city like population of year 2011, socio-economic data and other relevant information have been collected from Directorate of Census Operation Rajasthan. These data/ information gave been used as attribute data and joined with the thematic layers in GIS to prepare ward wise population map, population density map and economic status map.

2.1.3 Petroleum Location and Storage

Information about the location of petroleum product storage facilities, their storage capacity and safety measures were obtained from the Indian Oil Corporation Limited, Bharat Petroleum Corporation Limited and Hindustan Petroleum Corporation Limited. These data and information was used in creation of GIS database related to petroleum storage facilities as shown in Figure1.

2.1.4 Land Values

Values of land in Jaipur city is used to calculated the Economical Vulnerability at each location for petroleum fire. Economic data related to land and other resources have been obtained from Jaipur Development Authority and used in GIS to create relevant thematic layers.

2.1.5 Satellite Image

Satellite images are used to prepare landuse land cover map of the Jaipur city. Satellite images have been obtained from NASA's GLCF facility. Satellite images have been preprocessed in ERDAS Imagine to prepare landuse land cover and further built-up area.

2.1.6 Software Application

ARCGIS (version 10) developed by ESRI Inc. and ERDAS Imagine developed by Leica Geosystems Ltd. have been used in the present study. ERDAS Imagine has been used for processing of satellite images to prepare landuse/ landcover map and built-up area. ARCGIS has been used for creation of

GIS database and spatial analysis for vulnerability and risk assessment.

2.1.7 Other Information

Information about critical infrastructure, environmental assets, economicvalue shown in Figure 1 was obtained by surveying the area and also from Jaipur Development Authority and Jaipur Nagar Nigam.

2.2 Methodology

In the present study the risk of the petroleum fire in Jaipur city has been estimated, which is calculated by estimation of Exposure, Hazard and Vulnerability at ward level scale. For the assessment or each parameter, 500 m buffer is generated in GIS around each petroleum storage facility location. This buffer map (Fig. 3) has been overlaid in GIS (intersection) with the ward map having population density, economic value etc. attributes. Further DA was calculated in GIS using overlaid ward map and buffer map of storage facilities.

2.2.1 Risk

The risk is a function of three components: hazard, exposure (element at risk) and vulnerability. For example in case of risk of human losses, the element at risk is the population exposed. The occurrence of hazard is refers as the frequency of returning period at a given magnitude, while the vulnerability is “the degree of loss to each element when a hazard of a Specific severity occur” (Blaikie et al., 1994). A hypothesis was made that risk is calculated by a multiplicative formula which described in the simplified Equation known as Disaster Risk Index (DIR). This is used to describing the severity of risk for a study area, indicating the increasing or decreasing risk with the increasing or decreasing the value of DIR.

$$\mathrm{DRI} = \frac{\mathrm{H} + \mathrm{E} + \mathrm{V}}{3}$$

Where,
DRI – Disaster Risk Index, Describing the Risk, H- Hazards, depending on the frequency and intensity of hazards, E - Total population of affected areas, V - Vulnerability, depending on the social, physical, and economic status of affected areas),

2.2.2 Hazard

A hazard is the probability of occurrence of a physical phenomenon, which may threaten human lives that lead to injuries, property damage or dysfunction of social system and economic systems or the degradation of natural ecosystem. This is calculated from the probability of occurrence and intensity of the hazard that may occurred. The amount of petroleum product storage at different locations in the study area is used to calculate the intensity of the hazard that may occur, while the numbers of storage locations are used to calculate the probability of occurrence of hazard. Further, Hazard Severity Index (HSI) has been calculated using, intensity of hazard and probability. The HSI may have a range of values indicating increasing of severity with increase in its value. The HSI can be calculated as –

$$\mathrm{Hazard} = \frac{\mathrm{Intensity\ X\ Probability}}{\mathrm{Area}}$$

Where,
Intensity is refers as the amount of storage of each petroleum material and probability is the no. of storage in each ward.

2.2.3 Exposure

Exposure refers to the disaster prone assets (referred also as elements at risk) present in hazard affected areas, which are subject to potential losses. Exposure is the degree to which human population at risk is measure of exposure can include the number of people or types of assets in a specified location or area.
The exposure is calculated as number of peoples per unit area of the study area i.e. the population density, calculated as follows.

$$\mathrm{E} = \frac{\mathrm{Pop.}}{\mathrm{Area}}$$

Where,
E – Exposure
Pop. – Population, i.e. the population of ward
Area – Area under Ward

2.2.4 Vulnerability

Vulnerability is the condition determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the adverse impact of a hazard. Vulnerability can be calculated in the form of Vulnerability Index (VI), as the average of the all different type of Vulnerabilities i.e. Social Vulnerability, Physical Vulnerability, Environmental Vulnerability, Economical Vulnerability, Critical infrastructure Vulnerability. The increasing or decreasing Vulnerability Index indicates susceptibility of community for the particular Hazard in proportion to the value of VI, respectively.

$$VI = \frac{SV+PV+EnV+ECV+CIV}{5}.$$

Where,

VI = Vulnerability Index, SV = Social Vulnerability, PV = Physical Vulnerability, EnV = Environmental Vulnerability, EcV = Economical Vulnerability, CIV = Critical infrastructure Vulnerability

2.2.4.1 Social Vulnerability

Social vulnerability is the vulnerability which associated with a lack of resources to mitigate, cope with or recover from disaster or the population that lack of self-recovering capability. For example population under age 10 and above 60 lies under the category of social vulnerability. The social vulnerability can be presented in the form of Social Vulnerability Index (SVI). The SVI indicates increase or decrease in vulnerability corresponding to its increasing or decreasing value, respectively. The SVI can be calculated as

$$SVI = \frac{\text{Population (age } 10 > or < 65)\text{X DA Area}}{\text{Total Area of Ward}}$$

Where,

SVI – Social Vulnerability Index, DA - Dissemination area or affected area under buffer zone.

2.2.4.2 Physical Vulnerability

Physical vulnerability is expressed in terms of exposure to unsafe conditions. The population of the study region which is found to be dangerously close to the potential sources of threat is known as physical vulnerability. The physical vulnerability is described in the form of Physical Vulnerability Index (PVI), which is the total population under the dissemination area or affected. Increasing or decreasing value of PVI indicates increase and decrease in physical vulnerability respectively. The PVI can be calculated as –

$$PVI = \frac{\text{Population X DA Area}}{\text{Total Area of Ward}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

Where,

PVI – Physical Vulnerability Index, DA - Dissemination area or affected area under buffer zone.

2.2.4.3 Environmental Vulnerability

Environmental vulnerability is defined as potential for environmental degradation due to the existence of a Hazard. It can be calculated as amount of pollutants produced per unit area from different petroleum fire facilities. Environmental vulnerability can be presented quantitatively in the form of Environmental Vulnerability Index (EnVI). The increasing or decreasing value of EnVI represents increase or decrease in Environmental Vulnerability, respectively. The EnVI can be calculated as –

$$EnVI = \frac{(AP\ X\ PF_P) + (AD X PF_D) + (AL X PF_L)}{3\ X\ \text{Total Area of Ward}}.$$

Where,

EnVI = Environmental Vulnerability Index, AP = Amount of petrol stored in ward, PF_P = Amount of CO_2 produce on burning of one liter of petrol, AD = Amount of Diesel stored in ward, PF_D = Amount of CO_2 produce on burning of one liter of Diesel, AL = Amount of LPG stored in ward, PF_L = Amount of CO_2 produce on burning of one liter of LPG.

2.2.4.4 Critical Infrastructure Vulnerability

The critical infrastructure elements such as educational facilities, hospitals, transportation facilities, highway segments, and railway, transit lines are exposed to probable fire disasters and become unsafe are comes under critical infrastructure vulnerability. This type of vulnerability is represented quantitatively in term of Critical Infrastructure Vulnerability Index (CIVI). The CIVI can be calculated as –

$$CIVI = \frac{\text{No.of Critical Infrastructure in ward X DA Area}}{\text{Total Area of Ward}}.$$

Where,

CIVI – Critical Infrastructure Vulnerability Index, DA – Dissemination Area

3. Result and Discussion

In this study, calculation of Hazard, Exposure and Vulnerability for the Jaipur city at the ward level is done, through which petroleum fire risk was obtained. Firstly required GIS layers namely Petroleum Locations Layer, Critical Infrastructure Layers, Ward Boundary Layer and Road and Railway Network were created and different types of data such as petroleum storage location, population density, etc. of Jaipur city were processed using ArcGIS.

For calculating petroleum fire risk, after creating various layers, different variables were calculated using GIS operations, each variable for the Jaipur city calculated were separately represented in tabular as well as Map in table1 and figure 4-12.

4. Conclusion

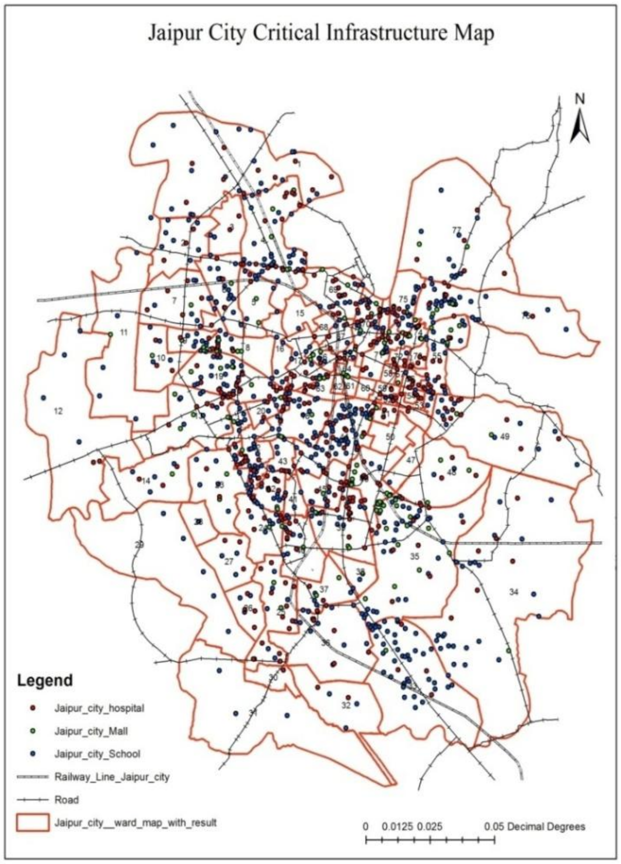
This study assesses the Petroleum fire risk for Jaipur city. Assessment is done to provide the information about Petroleum fire disaster risk atward level, using GIS and remote sensing. Various types of analysis for the assessment such as exposure assessment, hazard assessment and vulnerability assessment were done for the assessment of total fire risk in Jaipur city, the Capital of Rajasthan spread through 111.8 km^2. It was divided into 77 wards with population of 3073350. The overall assessment of the parameter that has been analyzed for the Risk assessment for Jaipur city Petroleum fire shows that central part of the city including Ward No. 67, 70, 69, 44 66 and 43 is under the high risk with varying disaster risk index from 1.214 to 1.699 with comparison to the outer part of the city.

Table1: Ward Wise Hazard, Exposure, and Vulnerability and Calculated Risk.

Ward	Hazard	Exposur	SV	PV	EnV	EcV	CIV	Vul	Risk
1	0.022	0.004	0.000	0.001	0.043	1.293	1.275	0.522	0.183
2	0.015	0.014	0.001	0.005	0.060	0.865	1.870	0.560	0.197
3	0.020	0.015	0.003	0.009	0.074	1.578	1.515	0.636	0.223
4	0.058	0.005	0.001	0.002	0.086	3.955	4.637	1.736	0.600
5	0.001	0.014	0.002	0.008	0.005	1.236	5.420	1.334	0.450
6	0.084	0.011	0.002	0.008	0.155	4.062	4.160	1.677	0.591
7	0.003	0.012	0.001	0.002	0.024	0.448	1.748	0.444	0.153
8	0.014	0.010	0.001	0.005	0.049	1.433	6.858	1.669	0.564
9	0.002	0.021	0.001	0.004	0.010	0.301	1.689	0.401	0.141
10	0.001	0.012	0.001	0.002	0.004	0.260	1.207	0.295	0.103
11	0.001	0.007	0.000	0.000	0.006	0.115	0.311	0.087	0.032
12	0.002	0.003	0.000	0.000	0.008	0.130	0.251	0.078	0.028
13	0.008	0.007	0.001	0.002	0.028	1.190	2.628	0.770	0.262
14	0.017	0.008	0.001	0.003	0.041	0.201	0.883	0.226	0.083
15	0.054	0.027	0.008	0.027	0.203	0.906	0.499	0.329	0.137
16	0.208	0.016	0.008	0.025	0.320	2.848	1.916	1.024	0.416
17	0.044	0.011	0.004	0.012	0.107	4.821	6.783	2.346	0.800
18	0.095	0.006	0.002	0.007	0.098	9.035	5.105	2.849	0.983
19	0.054	0.006	0.001	0.004	0.102	4.422	9.497	2.805	0.955
20	0.029	0.032	0.008	0.026	0.229	1.272	3.201	0.947	0.336
21	0.000	0.035	0.002	0.006	0.081	0.239	0.000	0.066	0.033
22	0.025	0.017	0.005	0.018	0.090	2.619	10.61	2.670	0.904
23	0.001	0.011	0.001	0.002	0.003	0.461	3.140	0.721	0.244
24	0.029	0.013	0.002	0.007	0.110	1.524	5.556	1.440	0.494
25	0.010	0.007	0.001	0.002	0.038	0.809	3.286	0.827	0.281
26	0.015	0.014	0.001	0.005	0.117	0.150	2.393	0.533	0.187
27	0.006	0.012	0.001	0.003	0.045	0.019	1.352	0.284	0.101
28	0.002	0.020	0.001	0.005	0.009	0.008	0.235	0.051	0.024
29	0.006	0.004	0.000	0.001	0.014	0.175	0.270	0.092	0.034
30	0.015	0.020	0.003	0.010	0.108	0.375	0.501	0.199	0.078
31	0.001	0.005	0.000	0.000	0.005	0.144	0.128	0.056	0.021
32	0.003	0.011	0.000	0.001	0.024	0.028	0.659	0.143	0.052
33	0.047	0.003	0.000	0.001	0.050	5.943	2.475	1.694	0.581
34	0.008	0.002	0.000	0.000	0.015	0.437	0.693	0.229	0.080
35	0.094	0.004	0.000	0.001	0.070	5.836	2.744	1.730	0.609
36	0.016	0.005	0.001	0.002	0.040	2.869	1.721	0.927	0.316
37	0.020	0.011	0.001	0.005	0.075	1.896	2.428	0.881	0.304
38	0.063	0.019	0.006	0.019	0.244	1.149	1.019	0.487	0.190
39	0.048	0.004	0.001	0.003	0.086	6.238	4.780	2.221	0.758
40	0.019	0.012	0.002	0.006	0.070	2.161	4.003	1.248	0.426
41	0.000	0.026	0.001	0.003	0.000	0.162	0.000	0.033	0.020
42	0.137	0.022	0.006	0.020	0.346	1.933	10.97	2.657	0.938

43	0.006	0.014	0.003	0.010	0.043	1.867	16.17	3.620	1.213
44	0.148	0.004	0.001	0.004	0.161	14.03	10.39	4.920	1.691
45	0.021	0.011	0.002	0.006	0.074	3.357	5.425	1.773	0.601
46	0.083	0.008	0.002	0.007	0.159	5.118	5.397	2.137	0.743
47	0.015	0.019	0.003	0.009	0.114	0.276	0.497	0.180	0.071
48	0.009	0.007	0.001	0.002	0.037	0.499	1.639	0.436	0.151
49	0.009	0.003	0.000	0.000	0.023	0.680	1.255	0.392	0.135
50	0.000	0.022	0.000	0.000	0.000	0.012	0.000	0.002	0.008
51	0.002	0.026	0.002	0.006	0.011	0.424	1.416	0.372	0.133
52	0.000	0.070	0.020	0.066	0.000	0.358	0.000	0.089	0.053
53	0.000	0.103	0.001	0.004	0.000	0.026	0.000	0.006	0.036
54	0.000	0.085	0.000	0.000	0.000	0.003	0.000	0.001	0.028
55	0.204	0.011	0.004	0.015	0.259	7.857	8.677	3.363	1.193
56	0.000	0.053	0.006	0.019	0.000	0.264	0.000	0.058	0.037
57	0.000	0.092	0.001	0.002	0.000	0.007	0.000	0.002	0.031
58	0.000	0.062	0.002	0.008	0.000	0.022	0.000	0.006	0.023
59	0.035	0.047	0.012	0.040	0.259	0.204	2.577	0.618	0.233
60	0.000	0.040	0.005	0.017	0.000	0.152	0.000	0.035	0.025
61	0.318	0.054	0.034	0.113	1.176	1.042	1.050	0.683	0.352
62	0.061	0.080	0.059	0.195	0.462	1.232	0.000	0.390	0.177
63	0.000	0.025	0.003	0.011	0.000	0.928	0.000	0.189	0.071
64	0.000	0.043	0.008	0.027	0.000	0.414	0.000	0.090	0.044
65	0.000	0.063	0.017	0.055	0.000	0.629	0.000	0.140	0.068
66	0.065	0.037	0.055	0.182	0.245	4.830	19.66	4.996	1.699
67	0.330	0.029	0.053	0.178	0.404	8.535	12.13	4.261	1.540
68	0.010	0.057	0.027	0.090	0.075	1.377	4.710	1.256	0.441
69	0.109	0.012	0.004	0.014	0.136	16.21	5.728	4.419	1.513
70	0.304	0.013	0.010	0.034	0.286	8.484	11.33	4.030	1.449
71	0.071	0.014	0.005	0.018	0.173	2.763	7.034	1.999	0.695
72	0.000	0.047	0.001	0.004	0.000	0.032	0.000	0.008	0.018
73	0.032	0.063	0.025	0.084	0.244	0.907	6.662	1.584	0.560
74	0.000	0.035	0.031	0.104	0.000	5.636	0.000	1.154	0.396
75	0.089	0.011	0.002	0.008	0.167	2.114	4.714	1.401	0.500
76	0.129	0.004	0.001	0.002	0.078	3.424	2.033	1.107	0.413
77	0.003	0.000	0.001	0.184	0.023	1.439	0.406	0.411	0.138

*****SV – Social Vulnerability; PV – Physical Vulnerability; EnV – Environmental Vulnerability; EcV – Economical Vulnerability



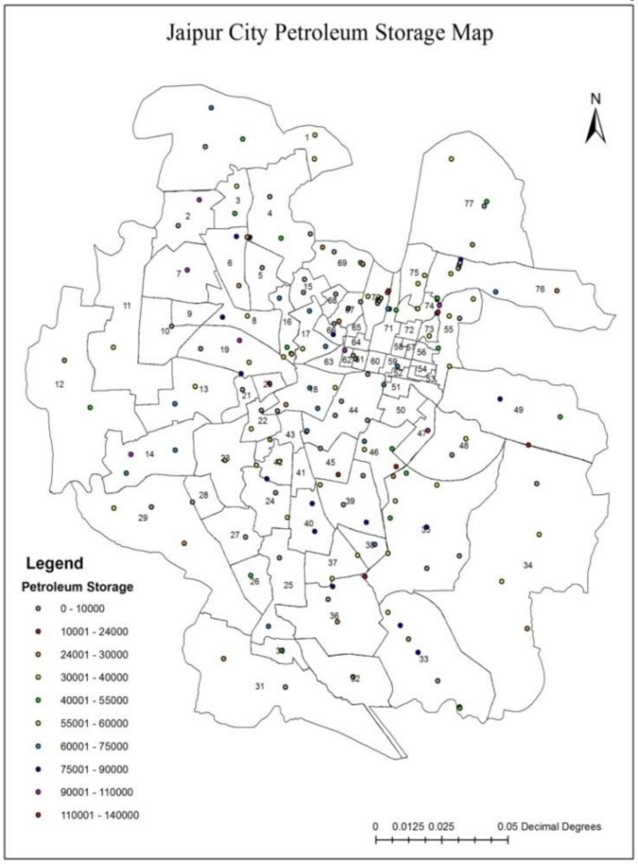
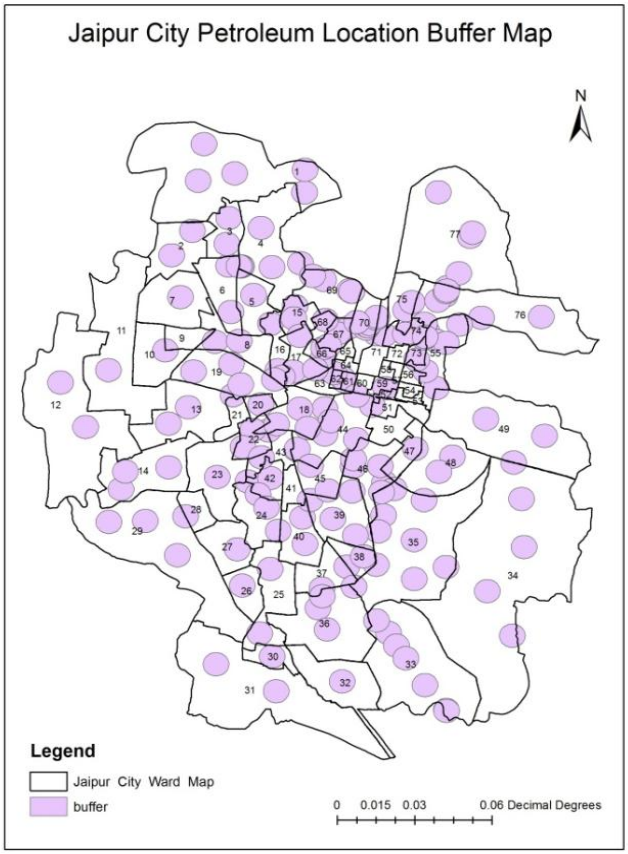


Figure 1) Jaipur city critical infrastructure**Figure 2)** Jaipur city petroleum storage map



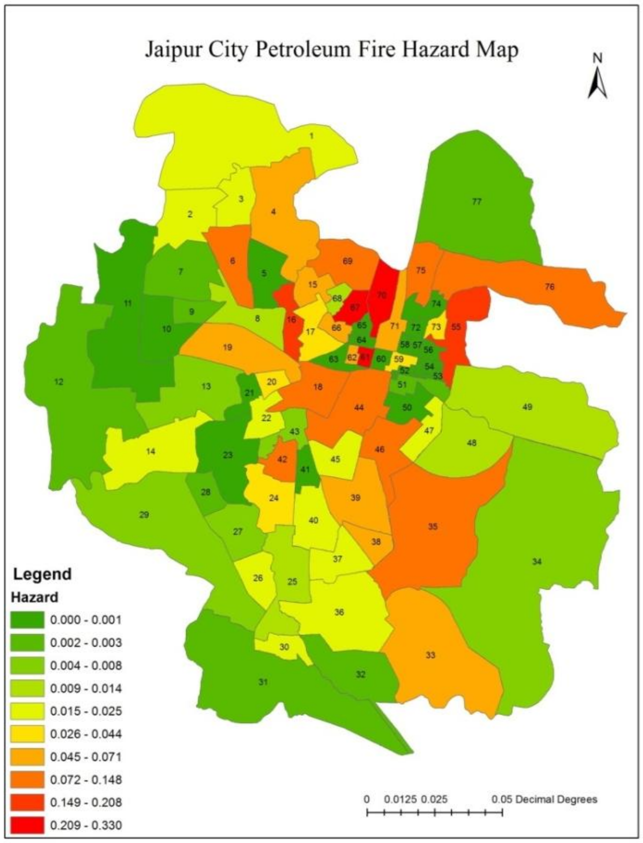


Figure 3) Jaipur city petroleum location Buffer **Figure 4)** Jaipur city petroleum fire hazard map

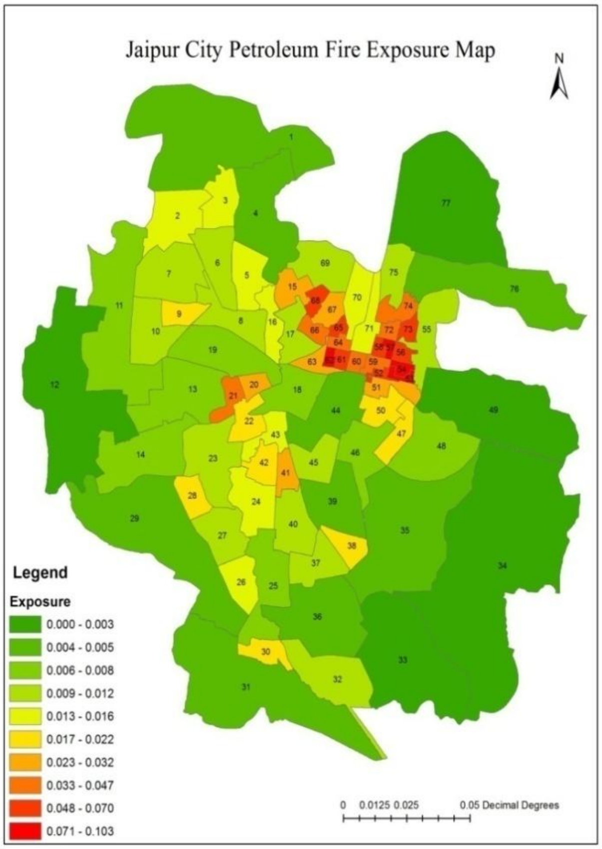


Figure 5) Jaipur city petroleum fire exposure map

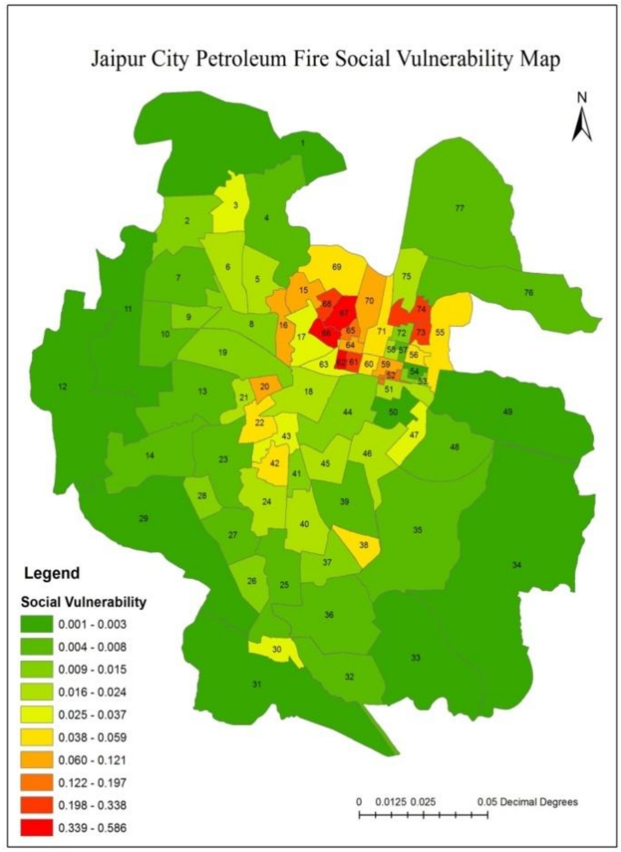


Figure 6) Jaipur city fire social vulnerability map

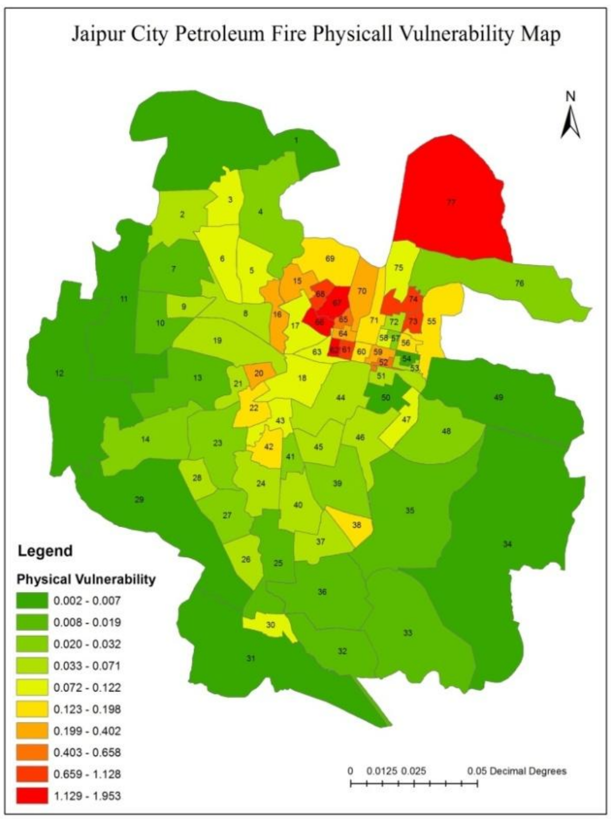


Figure 7) Jaipur city petroleum fire physical Vulnerability map

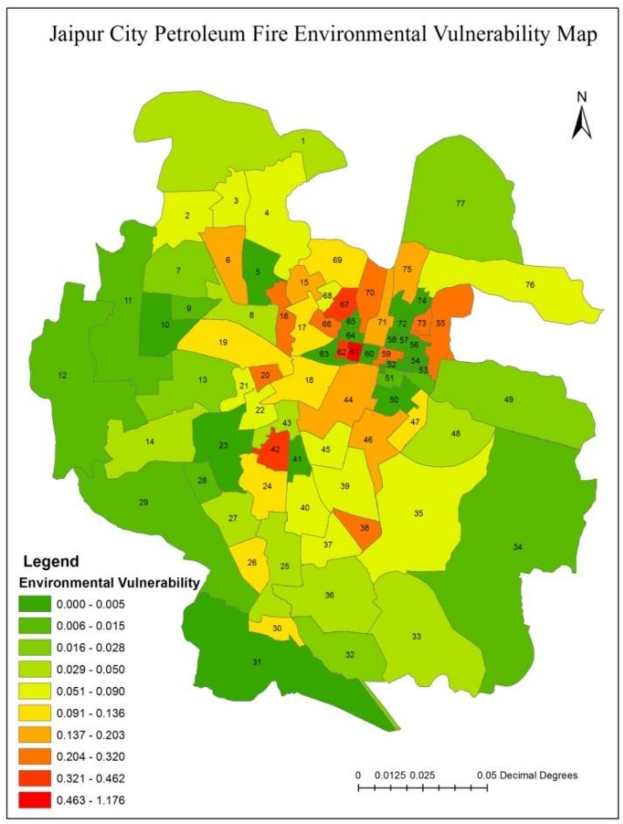


Figure 8) Jaipur city petroleum fire Environmental Vulnerability map

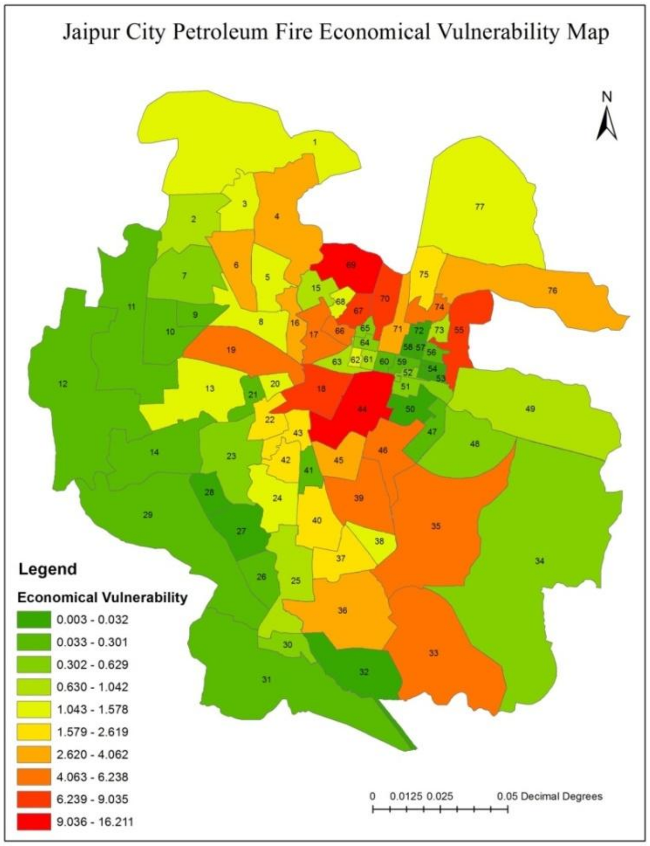


Figure 9) Jaipur city petroleum fire Economical Vulnerability map

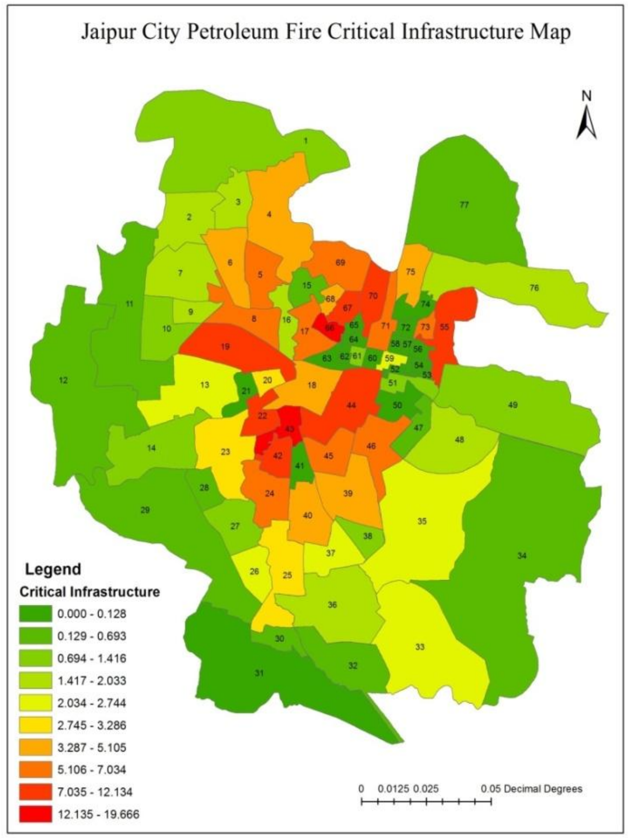
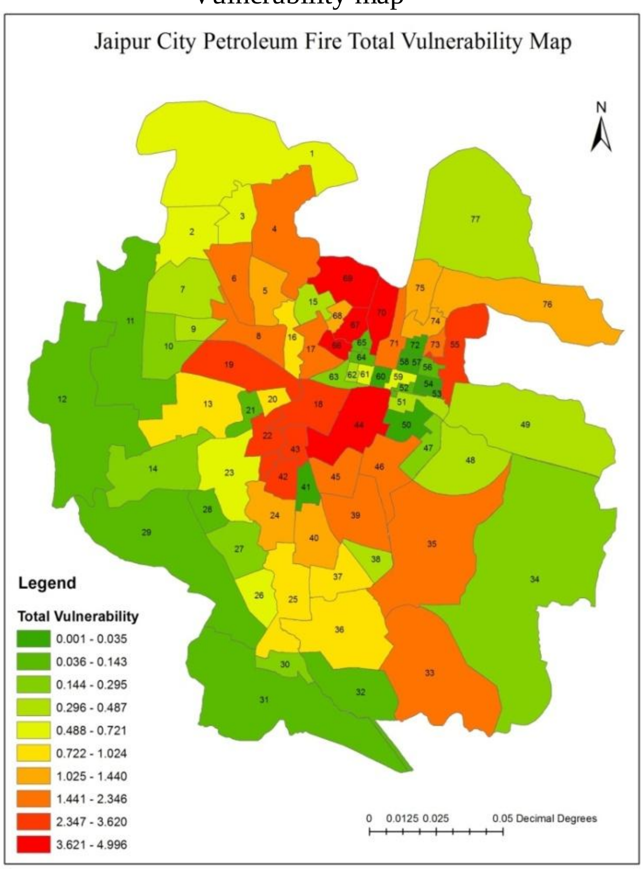


Figure 10) Jaipur city petroleum fire critical Vulnerability map



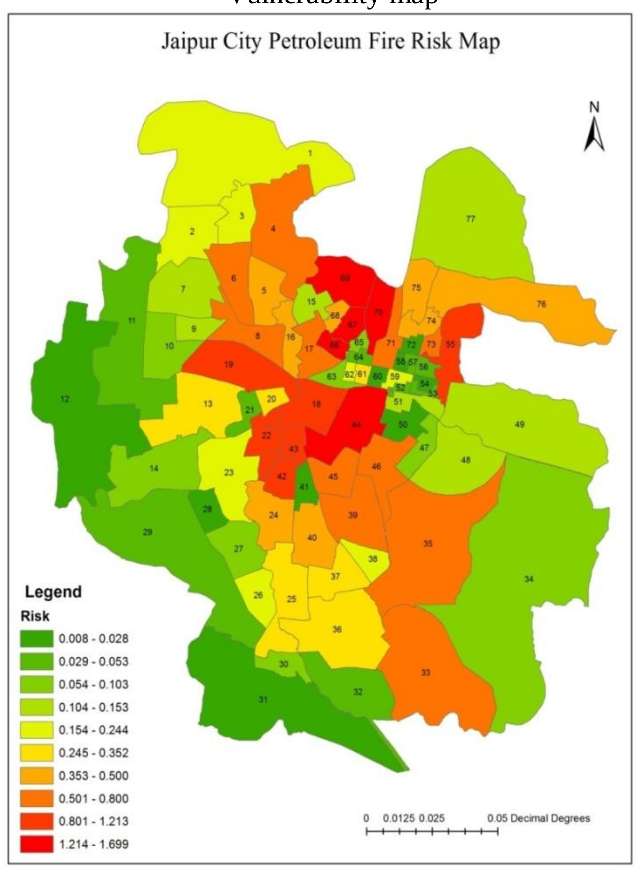


Figure 11) Jaipur city petroleum fire Vulnerability map **Figure 12)** Jaipur city petroleum fire Risk Map

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