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Environmental Vulnerability Assessment for South-West Region of Delhi using GIS based AHP tool

Nipra Sharma[1], Parmita Bose[2], Priyanka Kumari[3], Amarjeet Kaur[4*]
[1]University School of Environment Management, [2]GeoSpatial Delhi Limited, [3,4]Centre of Excellence in Disaster Management
Guru Gobind Singh Indraprastha University, Sector -16 C, Dwarka, New Delhi – 110078, India
E-mail: [1]niprasharma90@gmail.com, [2]parmita.bose@gmail.com,[3]doctorpriyankakumari@gmail.com, [4*]director.cdms@ipu.ac.in.

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Abstract

Delhi is developing rapidly and rushed unplanned decisions are giving rise to mixed land use land cover area. It is in turn increasing the infrastructural complexity and therefore making the country more vulnerable. Growing urbanization is becoming a global trend; the concern regarding environmental vulnerability is a major apprehension. Vulnerability is accessed with respect to social, infrastructural and environmental problems using Analytical Hierarchy Process (AHP) model. The class wise weights and category wise weights were assigned based on the Satty's Scale to all the 21 indicators discussed above. The pairwise matrix and CR value is calculated. The resultant vulnerability map developed using AHP tool was divided into five categories of vulnerability as: low, medium low, medium, medium high and high. The peri-urban area is more vulnerable than urban areas. In urban areas those regions where the development has taken place erratically is identified as vulnerable due to high population density. Also one more observation is made in this model, the social factors like illiteracy and unemployment are also observed to be impacting along with environmental aspect parameters. It was observed that only 10% of the total area falls under the high vulnerability class whereas 25% falls under medium high category.

1. Introduction

Urbanization and migration to urban areas of isolated populations is rapidly changing small cities into large metropolitan cities (Jain & Subbaiah, 2007). Emerging problems such as unplanned sprawl, inadequate housing facilities, traffic congestion, insufficient drainage, sewerage problem and lack of other amenities is observed due to rapid increase in urban migration (Bhagat, 2010). Yet in order to fulfill urban needs, access to certain facilities such as market, housing, water supply, electricity and adequate transportation is necessary (Aderamo and Aina, 2011). These environmental and infrastructures facilities are important and integral part for any community, but they are un-attended over space (Henderson, Shalizi, & Venables, 2001; Anderson & Pomfret, 2004; Kenbur and Venables, 2005). The availability and access to infrastructure varied resulting in spatial disparities within and between regions and localities (Madu, 2007).

The capital city, Delhi is observed to be loaded with the in-situ population growth along with high number of immigrants facing issues related to resource constraints. The socio-economic activities also have direct impact on the natural environment of the region and interact uniquely with the natural resources available such as water, land and air. For any urban environment, it is utmost important to identify the elements that are making the system vulnerable (Müller *et al*., 2011). In the indicator based approach, the state of exposure to any particular hazard for large urbanized area can be expressed in terms of indicators defining the influencing parameters. Studies devoted to the vulnerability factor stressed on selecting a unique variable for different areas and scales, depending on the limitations of the census design, therefore quite unique approaches could be adopted. In spite of these challenges, there are few fundamental group of indicators that ought to be incorporated into any study of social vulnerability and its analysis (Papathomas *et al*., 2007; Kappes *et al*., 2012; Thouret *et al*., 2014; Ettinger *et al*., 2016; Thennavan *et al*., 2016). The previous studies and literature available considered vulnerability to be dependent on variations in indicators such as age, gender, unemployment, dependence and property variables (Bartolini *et al*., 1982; Rossi *et al*., 2010).

For identification, comparison and multi-criterion decision making analysis of urban development, Remote Sensing (RS), Geographic Information System (GIS) and Analytical Hierarchy Process (AHP) are identified as a vital tool (Shukla, 2017 and Sandipan, 2013). For the purpose of quantitative environmental vulnerability analysis, various methods, such as Artificial Neural Network, Mathematical Modelling, Comprehensive Evaluation Method (Goda and Mastuoka, 1986), AHP - Analytical Hierarchy Process (Wang *et al*., 2008), Grey Evaluation Method, Fuzzy Evaluation Method, and Spatial Multi-Criteria Evaluation (SMCE) (Wilson *et al*., 2005). Regional environmental vulnerability is assessed using various methods, including fuzzy comprehensive assessment (Ippolito *et al*., 2010); land cover change assessment (Swetnam *et al*., 2011); landscape evaluation method (Menzel *et al*., 2012); and principal component approach (Zou and Kunihiko, 2017). AHP is also another most important evaluation tools (Nguyen *et al*., 2016), which is used in decision analysis by structuring the problem into a systematic hierarchical structure (Azarnivand *et al*., 2015). However, the judgments in the AHP are limited and unbalanced which do not consider the uncertainty and ambiguity (Azarnivand *et al*., 2015). Many researches on vulnerability assessment are executed using AHP tool. Hou *et al*. (2016) and Sahoo *et al*. (2016) analyzed the spatial and temporal distributions of ecological vulnerability in energy-rich areas using an Analytic Hierarchy Process (AHP). Both Liu *et al*. (2017) and Nguyen *et al*. (2016) used AHP to analyze the ecological vulnerability assessment index of a region with high population flow and large land use change from different perspectives.

In the urban and peri-urban regions of NCT Delhi, vulnerability assessment is to analyze the response of the resource system to changing environmental conditions with the over-exploitation by increasing population. The objective of this paper is to evaluate the environmental vulnerability at district level on the basis of the considered environmental, social and infrastructural aspect using AHP technique. This study has been conducted in order to understand the environmental issues with respect to the lifestyle of the residing people and their socio-economic status.

2. Materials and Methods

2.1 Study Area: The present study, carried out in the South-West District of NCT of Delhi, is located between 24 40’ and 28 29’ latitudes and 76 50’ and 77 14’ longitudes as depicted in fig 1. It covers an area of approximately 420 Sq. Km with a population of 2.29 million. The average population density of the area is 5458 persons per Sq. Km (Directorate of Economics and Statistics, 2022). The district covers both urban and peri-urban areas with 77 villages. The administrative block is divided into three sub-divisions namely Najafgarh, Vasant Vihar and Delhi Cantonment. The Najafgarh sub-division is predominantly a peri-urban area with the population of 74,073 (Census report, 2011). It is an interesting mix of both rural and urban lifestyles. Other prominent residential areas in the South-West District of Delhi are Uttam Nagar, Vasant Kunj, Vikas Puri, Najafgarh, Bijwasan, Vasant Vihar, and Janakpuri. The south and the west of the district also cover some parts of the Aravali Range.

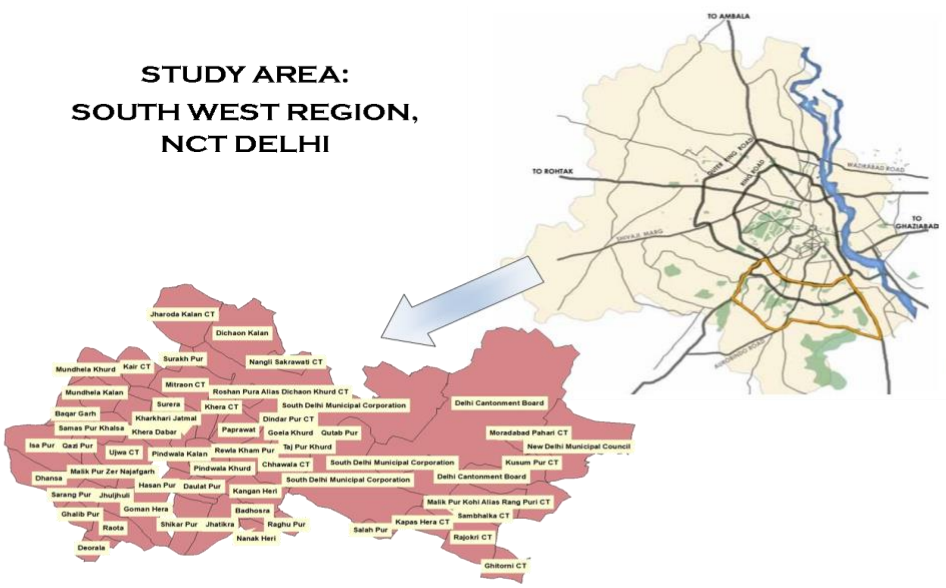

Fig 1: Study area South-west region of Delhi

2.2 Methods: Evaluation of environmental vulnerability inherently has multiple dimensions, and in order to evaluate the overall environmental vulnerability, it is crucial to analyze the interaction of all the contributing factors. In this study, a holistic approach is adopted to evaluate environmental vulnerability considering three aspects social, infrastructure and environmental. For the environmental parameters, Analytical Hierarchy Process (AHP) is applied in the selective six dominant influencing factors, such as, land use and land cover (LULC), ground water quality index (CCME WQI), surface water quality index (IWQI), groundwater level fluctuation (GWF), and annual average rainfall and temperature. Primary data collection has been executed for water sample and analyzed using existing water quality indices. Along with this data is generated for LULC. Secondary data available with government agencies were used for meterological parameters and ground water level. For the social aspect, indicators like female population, children population, illiteracy, household size were considered and the data collected through census and questionnaire execution was divided into equal intervals and reclassified in 3 categories: low, medium, high. For infrastructural aspect, indicators depending on the drinking water facilities, sewerage network, access to fresh water resources, and type of houses were considered and, the data collected through census and questionnaire execution was divided into equal intervals and reclassified in five categories: low, medium low, medium, medium high and high. For all the mentioned indicators, the weights were assigned based on the satty's scale and the pairwise matrix were generated. The interpolation maps were extracted using kriging interpolation tool with the above mentioned categories. The weights calculated through AHP technique were assigned and the final map was drawn using the tool. AHP tool is applied for all the individual main criteria and the resultant maps generated were again reassessed using AHP to generate the cumulative vulnerability map for southwest region of Delhi. The overall methodology adopted is mentioned in fig 2.

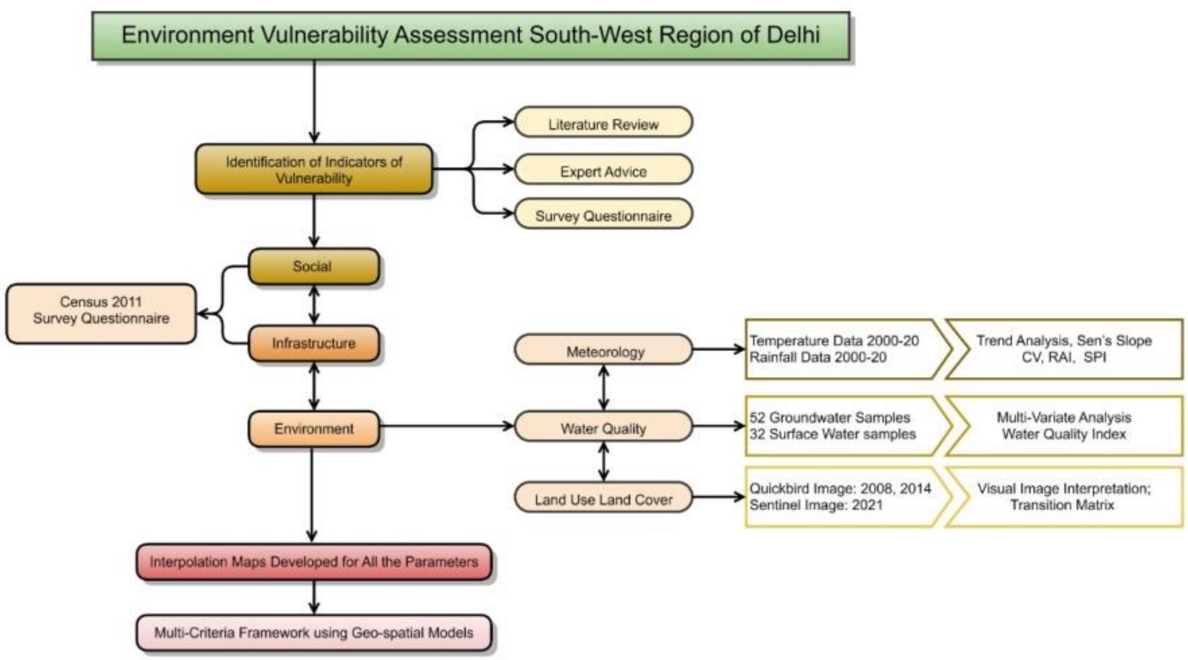

Fig 2: Overall methodology for environmental vulnerability assessment using AHP

Evaluating criteria in the respective levels of the given hierarchy and their comparison is done by assigning scores using a fundamental scale for a pairwise comparison matrix produced by Saaty (1980). Assigned priorities are given in 1–9 scale in each pair wise comparison, from which a vector of weights is obtained. The intensity of importance is represented by 1,3,5,7 and 9 as equal, weak, essential/strong, important and absolute important respectively. Whereas, 2,4,6,8 as intermediate values. The pair-wise comparisons are arranged into a matrix:

$$C = [C_{kp}] * (n*n)$$

Where, C_{kp} is the priority pairwise comparison for k-th and p-th criteria. A criterion weights, w¼ w_1; w_2; . . . ; wn½ are obtained from the pair-wise comparison matrix. The weights are calculated using the equation,

$$C(w) = k_{max} * w$$

Where, k_{max} is the largest eigen value of C (Saaty, 1980). The pairwise comparison matrix is then generated for the importance of criteria. Once the comparison is done, it is crucial to analyze the consistency ratio (CR) to decide whether the AHP is consistent or not. In the results, a CR value more than 0.1 indicates an error in calculations or possible inconsistencies made while carrying out the pairwise comparison (Saaty, 2008). The CR value is equal to 0.07 in current study. Re-categorization, appropriate rank scores, and assigning weight of sub-criteria and checking the constancy for the given layers are respectively estimated.

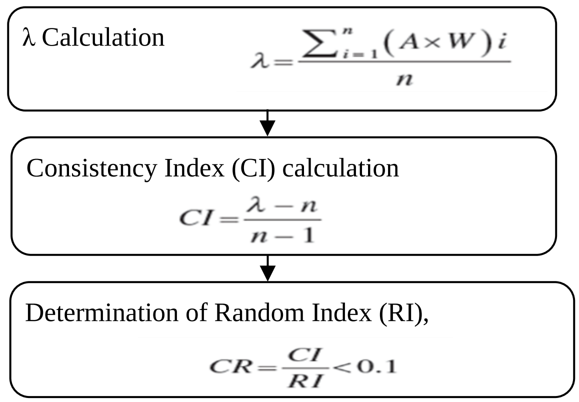

Fig 3: Detailed flow chart for steps followed in AHP

3. Results and Discussion

3.1 Development of pairwise comparison matrix: The pairwise matrix has been developed for the main and sub-factors using satty's method of AHP. Then, the relative weights were calculated for each factor using pairwise comparison method.

3.1.1 Assessment of Environmental parameters: For the current study, the water quality indices, Land Use Land Cover (LULC), annual average change in groundwater depth, annual average temperature and rainfall was taken into consideration as there were the impacting environmental factors. The pair wise matrix generated for all these sub-criteria is mentioned in table 1. The main contributors to a number of unfavorable environmental consequences such as: loss of productive agricultural land, deforestation, loss of water bodies, alteration of natural drainage, water contamination, microclimatic changes (Kalnay and Cai, 2003), reduced green spaces and increased land fragmentation (Grimm *et al*., 2000; Pickett *et al*., 2011; Miller, 2012; Li, 2013). This results in a major transformation of land use, and its surrounding environment (Kumar and Bhaduri, 2018). The environmental aspect is the most impacting factor in this study of vulnerability assessment for the study area as depicted in fig 4. All the environmental factors considered are observed to have equal contribution towards vulnerability. Among the meteorological parameters, rainfall has more impact than temperature as there are events of high rainfall observed in the course of last 20years (2000-2020) duration leading to urban flooding in Najafgarh sub-division. Whereas, in the Delhi Cantonment sub-division, the major environmental impacting parameter is the Land use/ Land cover change due to the emergence of dwarka sub-city and development of airports. Also with this poor ground water quality and shallow depth both contributes towards the environmental vulnerability of all the three sub-divisions. The water quality of najafgarh drain is also found to be poor which is again an environmental nuisance due to open dumping of waste in the drain. A drastic change in the quality of storm water drain is observed as the settlement across the drain increases, this is due to more human interference. Over the period of 20yrs the maximum change in the land use is observed in the dwarka and associated region due to the ongoing construction in different parts.

Table 1: Pair wise matrix of criteria for Environmental Factors

Environmental Factors	C1	C2	C3	C4	C5
C1	1	2	3	3	4
C2	0.5	1	2	6	5
C3	0.33	0.5	1	6	3
C4	0.33	0.16	0.16	1	2
C5	0.25	0.2	0.33	0.15	1
C1- Temperature; C2- Rainfall; C3- CCME WQI; C4-GW Depth; C5- IWQI					

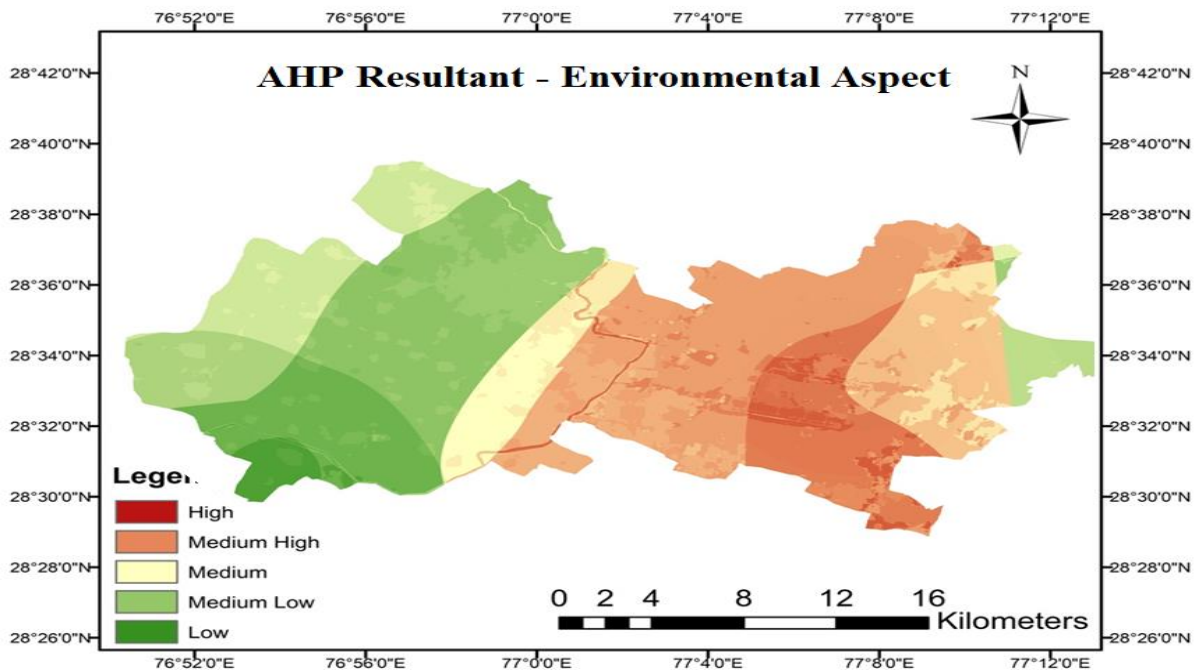

Fig 4: The resultant maps of AHP model explaining the environmental parameters

3.1.2 Assessment of Social parameter: As per the census data for every village and district, the western region i.e. the peri urban region is identified as more vulnerable than the urban areas as depicted. The table 2 depicts the pairwise matrix generated through satty's scale. As per census 2011, Delhi's literacy rate is 86.2%. The literate population percentage for the study area ranges from 62% to 85% in different villages and sub-districts. The peri-urban region has low literacy rate and high unemployment. In Delhi, average household size and female population was found to be high all through the district. The illiterate and unemployed population was also found to be in good numbers in this district as it covers the peri-urban area as well. The elderly population was found to be illiterate in both urban and peri-urban areas making them vulnerable.

The category wise interpolation map developed for social aspects shown in fig 5 depicts the vulnerability under three classes: low, medium and high. The western zone of the South-West region is highly vulnerable. Some parts of the southern region fall under highly vulnerable class, while the rest under medium vulnerable. Whereas, the cantonment sub-division falls under the category of low vulnerable. Among the vulnerable groups, the female population suffer more due to their sector-specific employment (most women being teachers, nurses or house-helps), their lower wages than men with equivalent education and knowledge, plus the additional family care responsibilities that they are burdened with naturally and particular cultural norms that keep them in a patriarchal oppressed state (Cutter *et al*., 2012). Along with this the children and elderly population is also considered as vulnerable towards any environmental calamity. Appropriating these factors, populations including more women, old-aged dependents and children are considerably more susceptible to disasters (Khan, 2012). This can vary with population density, an indicator that reflects urban expansion; and a region that is going through economical and infrastructural growth which will naturally have a population, more vulnerable as compared to others (De OliveiraMendes, 2009; Cutter *et al*., 2012).

Table 2: Pair wise matrix of criteria for Social Factors

% Female	C1	C2	C3
C1	1	3	5
C2	0.33	1	3
C3	0.2	0.33	1
% Population <6yr	C1	C2	C3
C1	1	3	5
C2	0.33	1	3
C3	0.2	0.33	1
% Illitrate	C1	C2	C3
C1	1	3	5
C2	0.33	1	3
C3	0.2	0.33	1
% Not working Population	C1	C2	C3
C1	1	3	5
C2	0.33	1	3
C3	0.2	0.33	1
Average Household Size	C1	C2	C3
C1	1	3	5
C2	0.33	1	3
C3	0.2	0.33	1
C1 - Low; C2- Medium; C3- High			

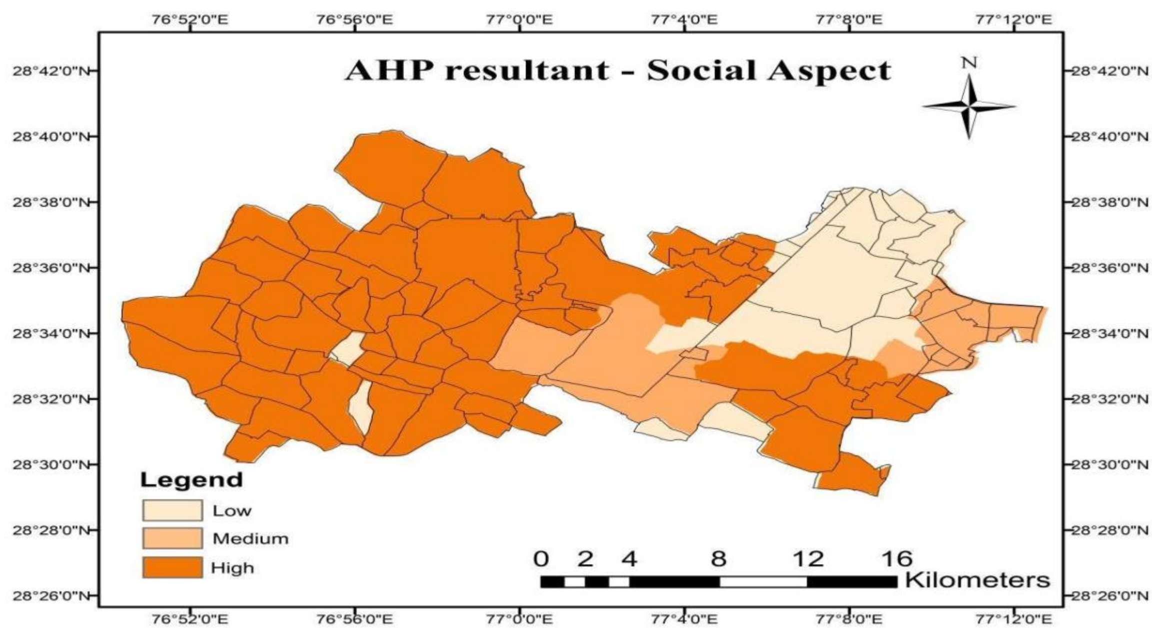

Fig 5: The resultant maps of AHP model explaining the social parameters

3.1.3 Assessment of Infrastructural parameters: The infrastructural facilities are also under constraint in some part of the given study area. The population living in the underprivileged sections of the NCT of Delhi, unauthorized colonies and villages, JJ clusters still do not have a proper accessible pipeline water supply and sewage disposal system. The percentage of houses having access to sewerage systems are found to be <20% in the western region i.e. the peri-urban area, the rest of the district have well defined sewerage systems. The pair wise matrix for the sub criteria is mentioned in table 3. As the South-West district depends more on the groundwater, the percentage of houses having tubewells and borewells are found between 60-80%. There is no check on the tube well/borewell connections by the agencies. Also the access to drinking water is found to be <40% in many localities/villages. As there are no proper water pipelines in the peri-urban areas just like no proper sewerage network, water tankers are sent in major parts in order to fulfill the water demands. This also highlights the non-availability of treated drinking water.

Likewise for the infrastructural aspect, the resultant AHP vulnerability map is divided into 5 categories: high, medium-high, medium, medium-low and low vulnerable. The absence of a sewerage system was the major contributor along with septic tanks which are maintained by the individuals. The dependency on tube well/borewell was high in this region due to no or low water supply which again contributes in high vulnerability. The urban area has access to all the infrastructure and transport facilities yet they also suffer from high vulnerability. All the sewerage collected is fed into the Najafgarh drain without any preliminary treatment. This affects the water quality of the drain and causes environmental vulnerability. It is identified from the fig 6 that the locality of Dhansa and Deorala falls under the category of highly vulnerable. This may be attributed by the low or no availability of infrastructural facilities. The areas of Dichaon Kalan, Jharoda Kalan fall under medium-high vulnerable category as they have unauthorized colonies with no access to basic facilities. In the Vasant Vihar subdivision, a small path near Mahipalpur is also observed to fall under medium-high vulnerability class as studied through questionnaire survey and found to be a small unauthorized colony with no basic life-supporting facilities. Along with this, Issapur Khera and Jhulhjuli village also fall in the same category with low vulnerability.

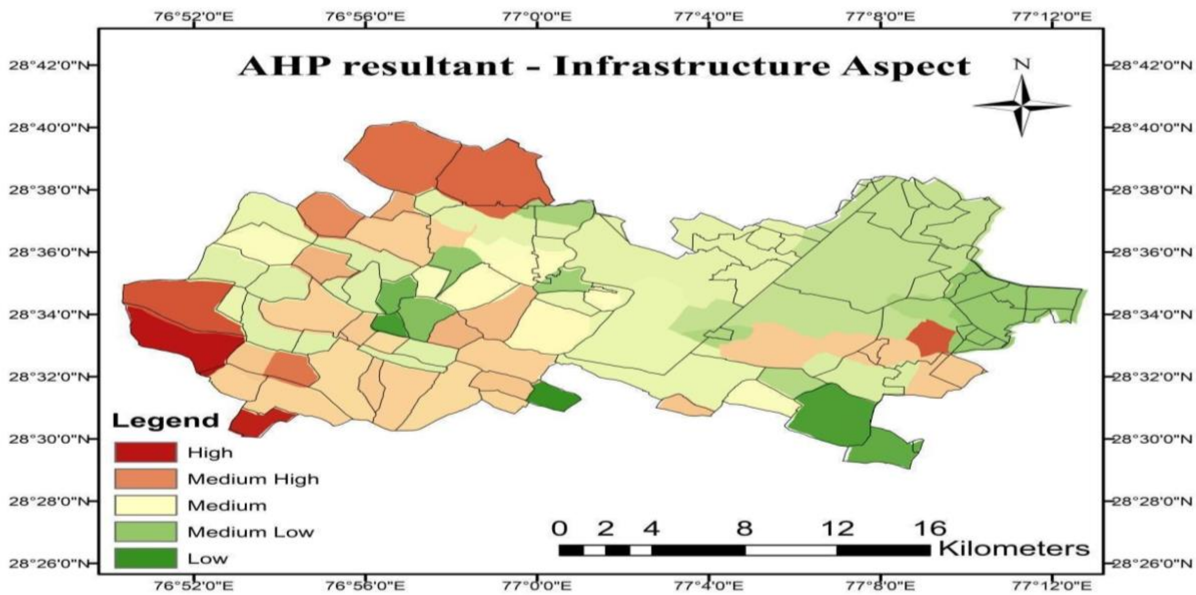

Fig 6: The resultant maps of AHP model explaining the infrastructure parameters

3.2 Assigning weights to the influencing parameters: The major impacting factors for environmental vulnerability were identified on the basis of previous studies and expert opinion. Additionally, the other impacting local level factors were determined based on the questionnaire survey executed across the local people and experts. Majorly, three main criteria were chosen to achieve the aim of this study. Socio-economic factors, environmental factors, infrastructural factors were the main criteria used in this research. The sub-factors derived from each main criterion as mentioned in the table 4, table 5 and table 6 below.

3.3 ***Cumulative Vulnerability assessment using AHP tool:*** The final output extracted by the AHP divided the study region into five categories: low vulnerable, medium-low vulnerable, medium vulnerable, medium high vulnerable and high vulnerable as depicted in fig 7. The most vulnerable region is the western part of the South-West region and parts of central southwest region is also observed to fall under highly vulnerable category. There are multiple factors studied above contributing for the resultant AHP vulnerability map. In the western part i.e. the peri-urban area, the lack of infrastructural facilities majorly defines the vulnerability of that area. Environmental factors like poor groundwater quality and land use change are contributing for the parts in the central region falling under highly vulnerable category.

Table 3: Pair wise matrix of criteria for Infrastructural Factors

Untreated tap water	C1	C2	C3	C4	C5
C1	1	0.33	0.2	0.14	0.11
C2	3	1	0.33	0.2	0.14
C3	5	3	1	0.33	0.2
C4	7	5	3	1	0.33
C5	9	7	5	3	1
Treated tap water	C1	C2	C3	C4	C5
C1	1	3	5	7	9
C2	0.33	1	3	5	7
C3	0.2	0.33	1	3	5
C4	0.14	0.2	0.33	1	3
C5	0.11	0.14	0.2	0.33	1
Outside the house	C1	C2	C3	C4	C5
C1	1	0.33	0.2	0.14	0.11
C2	3	1	0.33	0.2	0.14
C3	5	3	1	0.33	0.2
C4	7	5	3	1	0.33
C5	9	7	5	3	1
Inside the house	C1	C2	C3	C4	C5
C1	1	3	5	7	9
C2	0.33	1	3	5	7
C3	0.2	0.33	1	3	5
C4	0.14	0.2	0.33	1	3
C5	0.11	0.14	0.2	0.33	1
Tubewell	C1	C2	C3	C4	C5
C1	1	0.33	0.2	0.14	0.11
C2	3	1	0.33	0.2	0.14
C3	5	3	1	0.33	0.2
C4	7	5	3	1	0.33
C5	9	7	5	3	1
Handpump	C1	C2	C3		
C1	1	0.33	0.2		
C2	3	1	0.33		
C3	5	3	1		
Sewerage system	C1	C2	C3	C4	C5
C1	1	3	5	7	9
C2	0.33	1	3	5	7
C3	0.2	0.33	1	3	5
C4	0.14	0.2	0.33	1	3
C5	0.11	0.14	0.2	0.33	1
Septic tanks	C1	C2	C3	C4	C5
C1	1	0.33	0.2	0.14	0.11
C2	3	1	0.33	0.2	0.14
C3	5	3	1	0.33	0.2
C4	7	5	3	1	0.33
C5	9	7	5	3	1
Temporary houses	C1	C2	C3	C4	C5
C1	1	0.33	0.2	0.14	0.11
C2	3	1	0.33	0.2	0.14
C3	5	3	1	0.33	0.2
C4	7	5	3	1	0.33
C5	9	7	5	3	1
Permanent houses	C1	C2	C3	C4	C5
C1	1	3	5	7	9
C2	0.33	1	3	5	7
C3	0.2	0.33	1	3	5
C4	0.14	0.2	0.33	1	3
C5	0.11	0.14	0.2	0.33	1

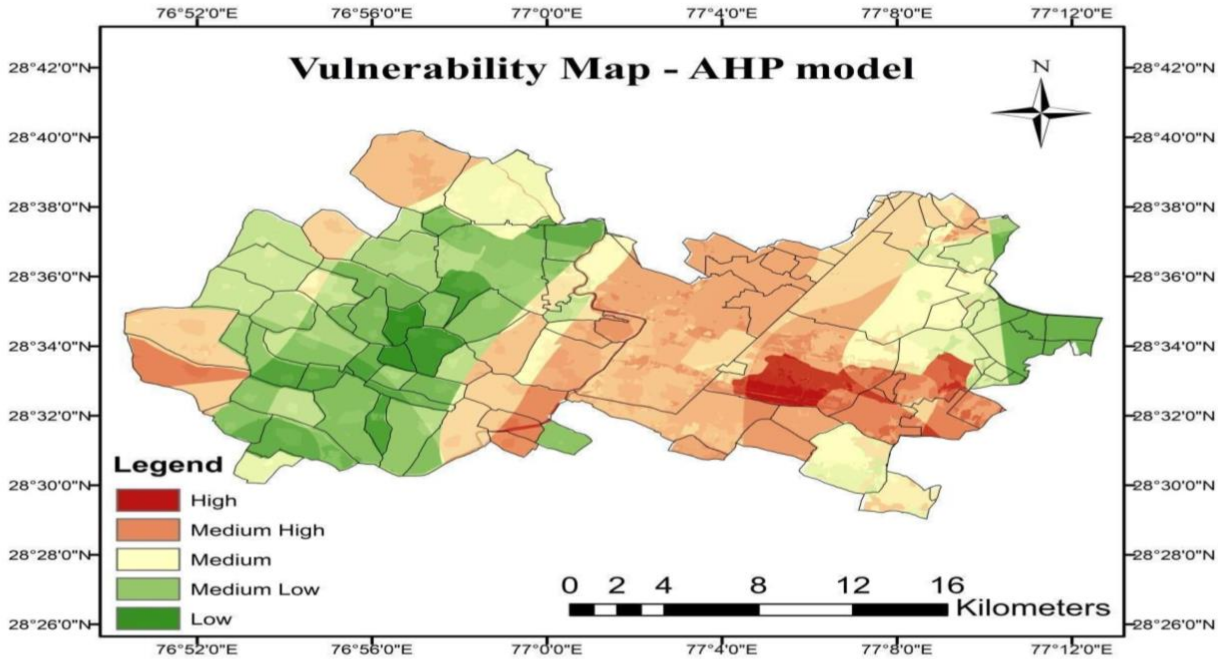

Fig 7: The resultant maps of AHP model explaining the overall vulnerability

Table 4: Weights of criteria for Environmental Factor**s**

Main Criteria	Weight	CR	Criteria	Weight	Sub-criteria	Weight	CR	∑weight
Environmental Factors	0.46	0.076	rainfall	0.07	Below normal	0.11	0.04	0.008
					Normal	0.26		0.018
					Above normal	0.63		0.044
			CCME WQI	0.1	Excellent	0.21	0.04	0.021
					Good	0.11		0.011
					Fair	0.045		0.005
					Marginal	0.218		0.022
					Poor	0.110		0.011
			IWQI	0.1	No restriction	0.201	0.09	0.020
					Low restriction	0.110		0.011
					Moderate restriction	0.045		0.005
					High restriction	0.063		0.006
					Severe restriction	0.028		0.003
			GW Depth	0.1	Low	0.110	0.09	0.011
					Low - middle	0.057		0.006
					Middle	0.029		0.003
					Middle - high	0.015		0.001
					High	0.018		0.002
			LULC	0.07	Agriculture	0.63	0.01	0.044
					Water-body	0.26		0.018
					Fallow land	0.11		0.008
					Built-up	0.63		0.044
					Change area	0.26		0.018
			Temperature	0.02	Low	0.26	0.05	0.018
					Medium low	0.26		0.005
					Medium	0.11		0.002
					Medium high	0.63		0.013
					High	0.26		0.005

Table 5: Weights of Criteria for Social Factors

Main Criteria	Weight	CR	Criteria	Weight	Sub-criteria	Weight	CR	∑weight
Social factors	0.2	0.114	% Female	0.05	Low	0.63	0.04	0.032
					Medium	0.26		0.013
					High	0.11		0.006
			% Population <6yr	0.05	Low	0.63	0.04	0.044
					Medium	0.26		0.018
					High	0.11		0.008
			% Illiterate	0.05	Low	0.63	0.04	0.032
					Medium	0.26		0.013
					High	0.11		0.006
			% Non-working	0.02	Low	0.63	0.04	0.019
					medium	0.26		0.008
					high	0.11		0.003
			Average household	0.03	low	0.63	0.04	0.019
					Medium	0.26		0.008
					High	0.11		0.003

Table 6: Weights of Criteria for Infrastructural Factors

Main Criteria	Weight	CR	Criteria	Weight	Sub-criteria	Weight	CR	∑weight
Infrastructural Factors	0.22	0.091	Treated tap water	0.05	Low	0.50	0.05	0.025
					Low medium	0.26		0.013
					Medium	0.13		0.007
					Medium high	0.07		0.003
					High	0.03		0.002
			Untreated tap water	0.05	Low	0.03	0.05	0.002
					Low medium	0.07		0.003
					Medium	0.13		0.007
					Medium high	0.26		0.013
					High	0.50		0.025
			Hand pump	0.03	Low	0.11	0.05	0.003
					Medium	0.26		0.008
					High	0.63		0.019
			Tube well	0.03	Low	0.03	0.05	0.001
					Low medium	0.07		0.002
					Medium	0.13		0.004
					Medium high	0.26		0.008
					High	0.50		0.015
			Within premises	0.03	Low	0.50	0.05	0.015
					Low medium	0.26		0.008
					Medium	0.13		0.004
					Medium high	0.07		0.002
					High	0.03		0.001
			Outside premises	0.03	Low	0.03	0.05	0.001
					Low medium	0.07		0.002
					Medium	0.13		0.004
					Medium high	0.26		0.008
					High	0.50		0.015
			Sewer system	0.03	Low	0.50	0.05	0.015
					Low medium	0.26		0.008
					Medium	0.13		0.004
					Medium high	0.07		0.002
					High	0.03		0.001
			Septic tank	0.03	Low	0.03	0.05	0.001
					Low medium	0.07		0.002
					Medium	0.13		0.004
					Medium high	0.26		0.008
					High	0.50		0.015
			Permanent house	0.03	Low	0.50	0.05	0.001
					Low medium	0.26		0.002
					Medium	0.13		0.004
					Medium high	0.07		0.008
					High	0.03		0.015
			Temporary house	0.03	Low	0.03	0.05	0.015
					Low medium	0.07		0.008
					Medium	0.13		0.004
					Medium high	0.26		0.002
					High	0.50		0.001

The Delhi Cantonment sub-division is least vulnerable due to presence all the resources in well defined form. The Najafgarh subdivision is also found to be highly vulnerable due to over populated mixed land use area facing multiple challenges, whereas the Vasant Vihar sub division is moderately vulnerable due to the availability of all the amenities apart from poor water quality and shallow groundwater depth. In urban areas those regions where the development has taken place erratically is identified as vulnerable due to high population density. Along with this, those areas with major land use change from pervious to impervious surface are identified as vulnerable. Villages falling under high vulnerable category are Bhakargah, Raota, Daulatpur, Jhatikra. Although densely populated areas with more infrastructure services, the type of land use cover will also be considered as a prime factor in causing urban vulnerability (Krellenberg and Kabisch, 2016). Usage of land, informally, brings up extra challenges in vulnerability studies, especially within the present conditions of fast urban growth or urbanization. It is observed that no one single factor is contributing for the identified vulnerability in various parts. The poor ground water quality, shallow depth, major land use change sites and limited infrastructural facilities is responsible for observed regions falling under the high vulnerable and medium high vulnerable category.

The area is calculated for the different categories and depicted in the fig 8. It was observed that only 10% of the total area falls under the high vulnerability class whereas 25% falls under medium high category. The places where maximum land use change is observed along with poor water quality and shallow water depth falls under the category of high and medium high vulnerability.

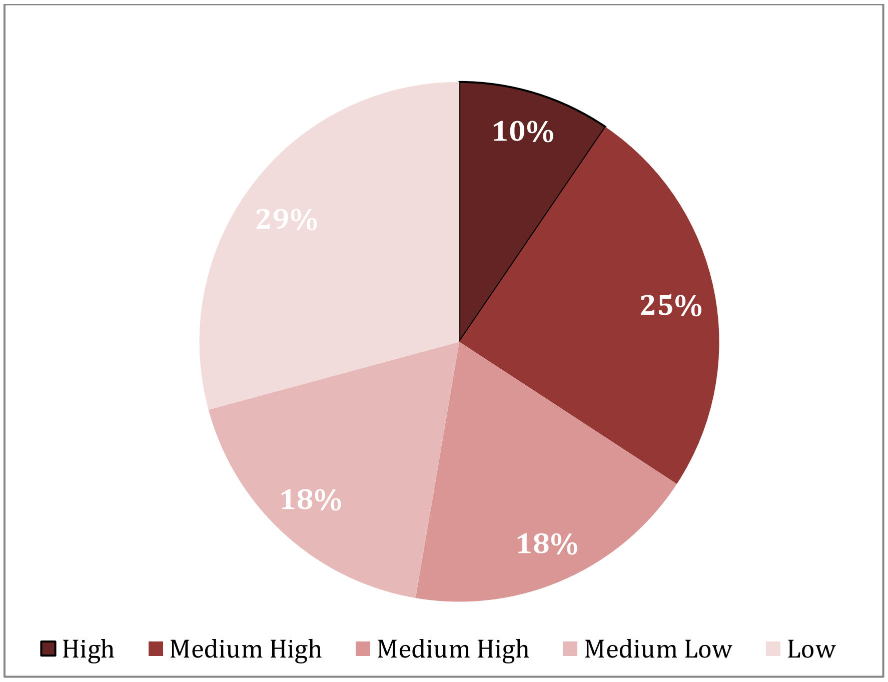

Fig 8: Category wise area estimation of AHP map

4. Conclusion

The vulnerability assessment of the South-West part of Delhi has unveiled the potential trend impacts of vulnerability, which will help develop mitigation and better management solutions for the studied area. Following key observations were made:

- The major part of the district falls under high and medium high class of vulnerability covering approximately 50% of the total area. The region of Najafgarh sub-division falls under medium high category. This is also observed in cumulative result of AHP for social aspect and environmental aspect.
- From the social and infrastructural aspect, Delhi cantonment and Vasant Vihar sub division are observed to have lower vulnerability as compared to Najafgarh sub-division. While the environmental issues can still be identified like ground water depletion and contamination along with land use change.

- Result of AHP for social and infrastructural aspect contributing for high vulnerability class of this area includes factors like illiterate and non-working population in the slum/villages of all the three sub-divisions, along with low infrastructural facilities. The illiterate and non-working population contributes towards high vulnerability as they have lifestyle constraints leading to ill maintenance of environmental and aesthetic values around (Birkmann *et al*., 2013).
- The too much dependency on groundwater for all water needs is primary issue faced in this district of Delhi as there is no other alternative source. This is on the other hand putting more pressure on the groundwater level decreasing the water table by 6.90m in pre monsoon and 6.08m in post monsoon season.
- The water quality of Najafgarh drain is also observed to be under severe and poor category of IWQI. The disposal of sewerage directly in the drain and the untreated effluent from treatment plants are the major sources. Along with this open dumping of waste and poor maintenance leading to degradation of this stormwater drain.
- The factors contributing for areas with medium high vulnerability are poor groundwater quality and quantity; poor quality of Najafgarh drain water impacting the surrounding area; impervious land use area. Here the target vulnerable group is the female population and not-working population along with high population density.

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