ISSN 1608-7844

Plan Plus, Volume-9, 2019 (107-113)

ASSESSING FIRE VULNERABILITY OF KHULNA CITY

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ABSTRACT

An accelerated wave of urbanization with rapid population growth is constantly changing the urban fabric of Khulna city, Bangladesh. This unrestricted growth amalgamated with urban disasters is amplifying vulnerability of urbanites to various hazardous incidents like a fire hazard, waterlogging and earthquake. In recent times fire hazard has become one of the predominant planning issues for city-dwellers, and city development and management authorities alike of Khulna city. This paper attempts to assess the spatial variation of fire vulnerability and explore root causes behind fire hazard of Khulna city through an index-based approach. The analytical hierarchy process (AHP) is adopted for developing index which weights 5 categories and 11 sub-categories of factors responsible for fire hazard of the city. Three reverend experts are interviewed for deciding weights in the AHP process. Geographic Information System (GIS) is used for extracting required variables from a digitized physical feature and land-use maps of the city and also for mapping the spatial variation of fire vulnerability across the city. Findings of the research suggest that fire vulnerability of 31 wards of Khulna city can be categorized into three levels, viz., high, moderate and low. In Khulna city, 2 wards are found to be highly vulnerable with vulnerability score ranging from 0.49 to 0.60, 18 wards are found to be moderately vulnerable with vulnerability score ranging from 0.37 to 0.48 and 11 wards are identified to be low vulnerable with vulnerability score ranging from 0.24 to 0.36. From this assessment root causes of fire vulnerability across the city are also identified. Among all factors, land use, building density, building types, and population density are found to be most influential factors for spatial variation of fire vulnerability across Khulna city.

KEYWORDS: vulnerability, Spatial variation, Index, AHP, GIS

1. INTRODUCTION

In today's world, availability of improved infrastructure and services for living and better work opportunity stimulate high concentration of population in the urban areas. However, more than 1billion urban people are constantly facing disasters, in particular, cyclones, floods, earthquakes, fire, crime, and industrial accidents, because of the high concentration of population, residential and commercial buildings and; industries in these urban areas (IFRCRCS, 2016). Major rapid onset disasters as Nepal earthquake, the Indian Ocean tsunami had been successful in drawing appreciable international attention. But, small scale disasters like fire hazards at old Dhaka had been impuissant to attract sufficient international concern. The world had experienced 385 massive fire hazards within the year 2010-2015 and most of the fire hazards occurred in Asia. The number of total affected people in Asia is also highest, which is 57 percent of the total number of deaths from fire incidents (IFRCRCS, 2016). Latest available information shows that, Bangladesh experienced 8063 fire hazards and the total amount of losses was 296.4crore taka in the year 2013 (DDM, 2013).

Technically, fire vulnerability is a circumstance of being prone to or susceptible to damage or loss from fire hazard. It can be defined as a set of consequential conditions, which adversely affect the ability to prevent, prepare for or respond to a hazardous fire event (Zaman, 2009). It involves those factors which determine the degree to which people's life, property and assets are put at risk of fire. Since, within a city population growth is highest in informal settlements, where housing conditions are poor with minimum or virtually no protective infrastructure and services available, these places are generally found to be more vulnerable. Besides, lack of access roads in any area of the city could stop fire engines from getting into the site of fire hazard and fire spreads to neighboring houses and causes massive fire hazard (IFRCRCS, 2010). Organic nature of growth of the cities is historically identified as one of the main reasons for fire incidents in the cities. For instance, the Great Fire of London in 1666 was one of the most catastrophic fire hazards in the world's history. One-third of London was destroyed, where 13200 houses, 87 churches were damaged. The hazard had also a devastating effect on the lives of the people from all social strata (Hepp, 2015). Before this fire incident, Landon city was an organically grown city, developed without any conscious city plan. Majority of the houses of the city were timber-framed construction, streets throughout the city were narrow and mostly blocked by the open market (Hanson, 1989). After this traumatic fire hazard first medieval city planning ushered in. New rules and planning standards were evoked to reduce the fire vulnerability factors so that the prevention of this hazard could be ensured (Hanson, 1989). Thus -fire vulnerability has become a matter of major concern in city planning and management. Besides, it also becomes obvious to planning professionals that fire vulnerability fluctuates across a city, even across the countries of world because of heterogeneity in spatial characteristics of its built environment (Adrianto, 2015)

Khulna, the third-largest city of Bangladesh experienced 190 fire incidents between the year 2014 and 2017. Therefore, it is of utmost importance to assess the spatial distribution of fire vulnerability of the city and to identify the key contributing factors behind this formidable hazard. Through this, this study is expected to provide essential inputs to disaster risk-sensitive physical planning for Khulna City.

2. LITERATURE REVIEW

Being an important urban planning and management issue, significant number of researches has proliferated over the years on fire vulnerabilities/ risks of cities and – their assessment. For instance, Fengying and Qi (2015) assessed the fire risk of CBD in Binhai new area of Tianjin, China. They used the AHP method, index-based approach, and ArcGIS technique to assess the fire risk of their study area. Authors also proposed a fire safety model of the Binhai city locating new fire stations. Buhler, et al., (2012) analyzed the demographic and socioeconomic vulnerability of fire hazard in Bariloche (Argentina). They used Principal Component Analysis and Akaike's Information Criterion for assessing fire vulnerability. Rahman, et al., (2015) did a GIS-based mapping of vulnerability to earthquake and fire hazard in Dhaka city, Bangladesh. For assessing fire hazard they used the methodology developed by ADPC. Their findings suggested that, Dhaka city is relatively more vulnerable to fire hazards than earthquakes. But, they did not consider the indexing approach for fire vulnerability assessment. Jalal (2012) assessed the fire risk of multi-storied buildings of Khulna city. He used the Delphi method and found that the height of the building is positively correlated with fire risk. However, he only focused on the multi-storied building without considering other land-uses of Khulna city. Zaman (2009) assessed the fire vulnerability of Ward no. 14 in the Dhaka Metropolitan area using chi-square test. He only focused on the socioeconomic aspects of fire vulnerability.

Fire Risk Assessment Method for Engineers (FRAME) developed from the GRETENER-method, is used as a tool to help fire protection engineer to define a sufficient and cost-effective fire safety concept for new or existing buildings. This method can easily be used to evaluate fire vulnerability of a certain building or a large area. In this study, a fire vulnerability index is developed modifying the FRAME approach. Fire vulnerability score of each the wards of Khulna city would be found from developed fire vulnerability indices. Finally, all wards of Khulna city are classified based on their fire vulnerability scores and the reason behind these vulnerabilities are identified.

3. STUDY AREA AND FACTORS CONSIDERED FOR ASSESSMENT

This study is conducted in Khulna city, one of the prominent economic hub of Bangladesh. This city with 31 wards (vide Map 01), has already experienced 190 fire incidents. Number of occurrences had been 29 in 2014, 27 in 2015, 65 in 2016 and 69 in 2017 (FSCD Authority, 2018). Thus, fire hazard, which is showing a increasing trend over the years has become a nightmare to the city dwellers.. It is, therefore, crucial to explore existing fire vulnerability scenarios for every ward of Khulna city and understand the spatial variation of fire vulnerability across city for devising a risk sensitive city plan in general and a city wide fire risk management plan in particular.

Map 1: 31 wards of Khulna city

Five categories and 11 sub-categories of factors have been selected for determining fire vulnerability scenario across Khulna city. In the current study, -factors considered are land use, building type, average road width, population density and building density. Among the factors, land use and building type have 8 and 3 subcategories respectively.

Land use

Patterns of land use arise naturally in a culture through its customs and practices. The land use of all wards of Khulna city can be classified into eight sub-categories, viz., vacant land, water-body, vegetation, residential area, commercial area, industrial area, public building and mixed-use area. Being a very populated city, Khulna has a very wee bit of vacant land available. About 7.58% of the total land area of Khulna city, which is 693.73 acres, is vacant. Among all wards, ward nos. 4, 16, 17, 18, 20, 26, 29 and 30 possess less than 0.5% vacant land of their individual jurisdictions. Then, ward nos. 21, 23, 24, 25, 27 and 28 have no vacant lands. Meanwhile, waterbody works as a very influencing factor in reducing fire vulnerability. The Khulna city has 4.20% of water bodies of its total area. Ward nos. 4, 5, 6, 8, 9, 12, 15, 19, 20 and 24 have only less than 0.5% water bodies of their individual jurisdictions and also the ward nos. 7, 10, 11 and 14 have no water bodies at all. Vegetation in Khulna city can be mainly categorized as agricultural land and small-scale urban forest. With the rapid development of the economy and society, more and more urban residential areas are becoming built-up with the increasing volumes and larger heights of buildings. But fire safety measures are not taken strictly in many of the residential buildings, so they are more susceptible to fire hazards. Therefore, quantity of residential area of a certain ward is an important factor for assessing vulnerability of fire hazards.

Commercial areas are the most congested areas in terms of building density and population density in a city. In Khulna city, ward nos. 13, 21, 22 and 27 have around 30% commercial areas within their respective boundaries. Industries could face significant loss to business through fire hazard for containing combustible and flammable materials. Hence, industrial areas are considered as one of the most influential sub-categories of factors for fire vulnerability assessment. In Khulna city, ward nos. 6, 9, 12, 14, 23, 28, 30 and 31 have more than 15% industrial areas within their respective areas. Mixed-use areas are highly vulnerable for the frequent occurrence of fire hazards due to existence of residential, commercial, administrative and industrial buildings within a mixed-use area without any segregation. In Khulna city, ward nos. 4, 14, 17, 18, 19, 21 and 28 have around 40% mixed-use areas within their jurisdictions.

Average road width

Roads are used as an emergency evacuation route by fire trucks during hazards. In Khulna city, the average road width is 8.476 meters and the lowest road width is 5.998 meters. The ward nos. 3, 16, 17, 21, 28, 30 and 31 have road width less than average road width of Khulna city, whereas word 7, 8, 10, 11, 12, 23 and 24 have road width more than the average road width of the city.

Building type

Buildings of Khulna city are classified into three sub-categories based on building materials viz., kutcha, semi-pucca and pucca. Kutcha and semi-pucca buildings are constructed using relatively more combustible building materials and pucca buildings are constructed using relatively less combustible building materials. Ward nos. 1, 2, 3, 4, 6, 11, 14, 22 and 31 have more than 40%

kutcha buildings and the ward nos. 5, 6, 8, 10, 11, 12, 18, 19, 20 and 22 have more than 40% semi-pucca buildings and ward nos. 7, 9, 13, 15, 16, 17, 21, 23, 24, 25, 26, 27, 28, 29 and 30 have more than 50% pucca buildings in respect to their total building within individual ward.

Population density

As the area with high population density is more prone to fire hazards, it is important to analyze the existing population density of each of the wards of Khulna City. The average population density of Khulna city is 79 persons per acre, while ward nos. 10, 11, 12, 14, 19, 20, 23, 25, 26 and 27 have population density around 140 persons per acre individually. Conversely, ward nos. 2, 3, 4, 13 and 30 have population density only around 25 persons per acre in each ward, which is much lower than the average population density of the city.

Building density

Number of buildings per acre area of each ward of Khulna city is calculated to define the variation of building density across Khulna city. The average building density of Khulna city is 4 buildings per acre area, whereas ward nos. 10, 11, 12, 14, 16, 17, 22, 28 and 29 have around 10 buildings per acre and ward nos. 1, 20, 24, 25 and 26 have around 1.5 buildings per acre.

4. METHODOLOGY

In this study, vulnerability factors are selected through a diligent reviewing of available literature. Availability of data, and opinion of experts are also considered for this selection. Analytic hierarchy process is used to produce an index of fire vulnerability which weights and prioritizes factors of vulnerability. Three reverend experts, who have extensive knowledge in disaster management field were interviewed for deciding priorities and weights. The AHP method includes three major steps. The first step is the generation of binary pairwise comparison matrices on a scale of 1–9, where, 1 indicating that the two elements are equally important, and 9 implying that one element is more important than the other (vide table 1). Pairwise comparison matrix is then normalized for each factors (Saaty, 1990). In the second step, the weights of different factors are calculated from Row Multiplied Value (RMV) in, un-normalized value and normalized value using the equation (1) and (2). In equation (2) m_i represents the un-normalized value of its factor and n represents the number of categories.

Un-normalized value, $m_i = \sqrt[n]{RMV}$ . . . . (1)

Normalized value $= m_i \div \int\left(\frac{n}{i=1}\right) m_i$ . . . .(2)

Table 1: Magnitude of Importance for Pair Wise Comparison

Intensity of importance	Definition
1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus

Table 1: Magnitude of Importance for Pair Wise Comparison (continued)

Intensity of importance	Definition
7	Very strong or demonstrate importance
8	Very, very stron g
9	Extreme importance

Source: Saaty, 1990

In the third step, weights of each of the factors and the consistency of estimations between judgments are measured. The consistencies are measured using consistency index and consistency ratio as shown in equations (3) and (4). In equation (3) L refers to the largest value of the pairwise comparison matrix. In equation (4) RI represents the random consistency index and CI represent consistency index.

$$\text{Consistency index, CI}=\frac{L-n}{N-1} \quad \text{(3)}$$

$$\text{Consistency ratio, CR}=\frac{CI}{RI} \quad \text{(4)}$$

If consistency ratio, CR is more than 10%, the pair wise comparison matrix is inconsistent and pairwise comparison must be re-performed between categories and sub-categories. The measured CR for, -vulnerability categories is 1.5% and for subcategories of land-use and building types are - 5.5% and 5.6% respectively, as shown in tables 2, 3 and 4. All of them are found to be less than 10% and hence found to be consistent.

Table 2: CR and Weights of Different Categories of Fire Vulnerability Factors

Consistency Ratio CR = 1.5%	Land use 1	Average road width	Population density	Building type	Building density	Weight 0.318
Land use	0.50	2.00	6.00	1.00	2.00	0.231
Average road width	0.17	1	5.00	1.00	2.00	0.051
Population density	1.00	0.20	1	0.17	0.50	0.273
Building type	0.50	1.00	6.00	1	2.00	0.126
Building density		0.50	2.00	0.50	1	

Table 3: CR and Weights of Different Sub-Categories of Land Use

Consistency Ratio CR = 5.5%	Water body	Vacant land	Vegetation	Public building	Residential	Industrial	Commercial	Mixed use	Weight
Water body	1	3.00	6.00	3.00	2.00	0.50	1.00	0.50	0.14
Vacant land	0.33	1	3.00	0.33	0.20	0.17	0.50	0.17	0.04
Vegetation	0.17	0.33	1	0.25	0.20	0.14	0.50	0.17	0.27
Public building	0.33	3.00	4.00	1	1.00	0.20	0.33	0.33	0.075
Residential	0.50	5.00	5.00	1.00	1	0.33	2.00	1.00	0.13
Industrial	2.00	6.00	7.00	5.00	3.00	1	3.00	2.00	0.07
Commercial	1.00	2.00	2.00	3.00	0.50	0.33	1	0.50	0.10
Mixed use	2.00	6.00	6.00	3.00	1.00	0.50	2.00	1	0.18

Table 4: CR and Weights of Different Sub-categories of Building Types

Consistency Ratio CR = 5.6%	Pucca	Semi pucca	Kutcha	Weight
Pucca	1	0.33	0.14	0.088
Semi pucca	3.00	1	0.33	0.243
Kutcha	7.00	3.00	1	0.669

Since each of the sub-categories are measured on different scales, so it is necessary to standardize values of each of sub-categories.

$$\text{Normalized value of Subcategory} = \frac{\text{So-Smin}}{\text{Smax-Smin}} \quad \ldots\ldots\ldots\ldots (5)$$

Equation (5), adapted from the Human Development Index (HDI) method (Hahn, 2008) is used for this standardization. In equation (5) -So refers to the value of the sub-category, Smax means the highest value and Smin refers to the lowest value. If the sub-category is negatively correlated with the category, to get the final value of that sub-category equation (6) is used (Pelling, 2003).

$$\text{Score of category} = \frac{\sum_{1}^{n} \text{Value of subcategories}}{\text{Number of subcategories}} \quad \ldots\ldots\ldots\ldots (7)$$

$$\text{Index score, } S = \sum_{1}^{n} WiSi \quad \ldots\ldots\ldots\ldots (8)$$

Equation (7) is used for getting the score of categories and for calculating index equation (8) is used, which is adapted from Fire Risk Assessment Method for Engineers (FRAME) and modified following HDI procedure (Hahn, 2008), where S means index score, n means number of categories, Wi means weight of categories I and Si means normalized score of categories i.

Land use score = (0.14*normalized value of waterbody) +(0.04* normalized value of vacant land) + (0.27*normalized value of vegetation) + (0.07*normalized value of public building) + (0.13*normalized value of residential area) + (0.07*normalized value of industrial area) + (0.10*normalized value of commercial area) + (0.18*normalized value of mixed use area). . (9)

Building type score = (0.088*normalized value of pucca) + (0.243*normalized value of semi pucca building) + (0.669*normalized value of katchabuilding). . (10)

Fire vulnerability index = (0.318*normalized value of land use) + (0.231*normalized value of average road width) + (0.051*normalized value of population density) + (0.273*normalized value of building type) +(0.126*normalized value of building density) . . .. . .(11)

The total weight of sub-categories of each category of factors is 1. To get the value of each category, all the normalized values of its sub-categories are multiplied with their respective weights. Then, results are added to calculate the value of the category of factors following equation (9) and (10). After normalizing the value of each category, they are multiplied with the weight of each category and added together to find the score of the index following equation (11).

Process of data analysis

Vulnerability value of each of the wards of Khulna city are gathered using proprietary data bases in quantitative forms and linked with GIS shape files. Frequency distributions, geo-processing and spatial analysis of proprietary GIS have been intensively used for analyzing spatial variations of fire vulnerability of Khulna City. Equations (9), (10), (11) are used to get the fire vulnerability index scores of each of the wards of Khulna city. Based on scores and natural breakdown classification of ArcGIS 10 all wards of Khulna city are classified into three categories, viz., low (0.248-0.365), medium (0.366-0.482) and high (0.483-0.600) vulnerable areas. Finally, a vulnerability map is –prepared to show the spatial variation of fire vulnerability across Khulna City (Vide Map 2).

5. RESULTS

The spatial variation of fire vulnerability is analyzed by reshaping the FRAME approach. By calculating fire vulnerability scores, ward 12, and ward 14 are found to be highly vulnerable (vide table 5). Ward nos. 2, 6, 7, 8, 9, 10, 11, 13, 15, 17, 19, 21, 22, 23, 24, 27, 28 and 29 are observed to moderately vulnerable and ward nos. 1, 3, 4, 5, 16, 18, 20, 25, 26, 30 and 31 are found to be less vulnerable wards of Khulna city.

Table 5: Fire Vulnerability Index Scores of all Wards of Khulna City

Ward nos.	Vulnerability Index Score	Vulnerability Status
1	0.25	Low vulnerable
2	0.45	Moderately vulnerable
3	0.27	Low vulnerable
4	0.27	Low vulnerable
5	0.28	Low vulnerable
6	0.38	Moderately vulnerable
7	0.39	Moderately vulnerable
8	0.46	Moderately vulnerable
9	0.46	Moderately vulnerable
10	0.47	Moderately vulnerable
11	0.46	Moderately vulnerable
12	0.60	Highly vulnerable
13	0.41	Moderately vulnerable
14	0.52	Highly vulnerable
15	0.38	Moderately vulnerable
16	0.32	Low vulnerable
17	0.39	Moderately vulnerable
18	0.34	Low vulnerable
19	0.38	Moderately vulnerable
20	0.29	Low vulnerable
21	0.39	Moderately vulnerable

Table 5: Fire Vulnerability Index Scores of all Wards of Khulna City (continued)

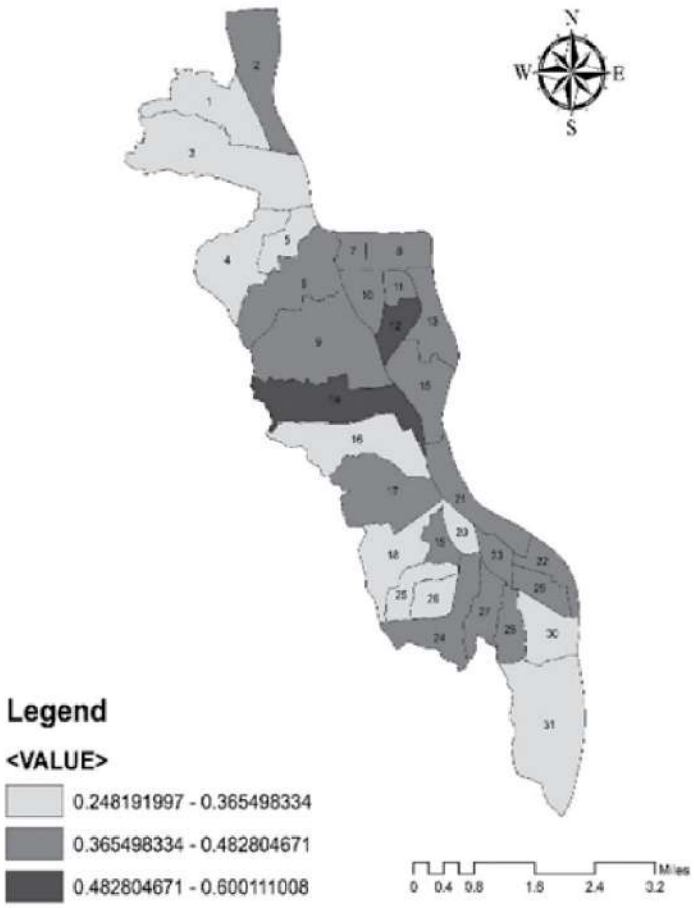
Ward nos.	Vulnerability Index Score	Vulnerability Status
22	0.41	Moderately vulnerable
23	0.40	Moderately vulnerable
24	0.41	Moderately vulnerable
25	0.31	Low vulnerable
26	0.27	Low vulnerable
27	0.41	Moderately vulnerable
28	0.44	Moderately vulnerable
29	0.38	Moderately vulnerable
30	0.29	Low vulnerable
31	0.30	Low vulnerable

Ward nos. 12 and 14 are spotted as highly vulnerable wards of Khulna city. Most dominant contributors to high level of their fire vulnerability is land use. Land use-related issues that affects fire vulnerability most for ward nos. 12 and 14 is waterbody. Ward no. 12 has only 0.5% water body of its jurisdiction and ward no. 14 do not have any water body at all, which decreases the firefighting capacity of those wards. Industrial areas containing combustible materials are more vulnerable than any other land uses and ward nos. 12 and 14 both have more than 15% industrial areas within their boundary. Unplanned area, mixed-use areas are generally thought to be vulnerable because of non-existence of any segregation among different land-use types in those areas. Ward no. 14 has 40% mixed-use area within its boundary, which makes the ward vulnerable to fire hazard. If the buildings are built using inflammable materials that kutcha or semi-pucca buildings are usually constructed of, those are more vulnerability to fire hazard. Ward no. 14 has more than 40% kutcha houses and ward no. 12 owns more than 40% semi-pucca houses of the total number of building stocks of each ward respectively. This factor, -amplifies their vulnerability to fire hazard. Vulnerability to fire hazard increases with increase of population density. Ward nos. 12 and 14, both have average population densities of around 140 persons per acre, is much higher than the average population density (79 persons per acre) of Khulna city, which makes those wards most vulnerable to fire hazard. Moreover, both ward nos. 12 and ward nos. 14 have building densities of 10 buildings per acre individually, which is the highest building density in Khulna city. This factor also influences their higher fire vulnerability.

There are different factors responsible for the ward nos. 2, 6, 7, 8, 9, 10, 11, 13, 15, 17, 19, 21, 22, 23, 24, 27, 28 and 29 of being moderately vulnerable. Ward nos. 21, 23, 24, 27 and 28 have no vacant land and the ward nos. 6, 8, 9, 15, 19 and 24 have only less than 0.5% water bodies within the boundary of each of the ward. Ward nos. 13, 21, 22 and 27 have around 30% commercial areas and ward nos. 6, 9, 23 and 28 have more than 15% industrial areas of their own. Ward nos. 2, 6, 11 and 22 of Khulna city have more than 40% kutcha buildings and the ward nos. 6, 8, 10, 11, 19 and 22 have more than 40% semi-pucca buildings respectively. Ward nos. 10, 11, 19, 23 and 27 have population density around 140 persons per acre within their respective jurisdictions. Ward nos. 10, 11, 17, 22, 28 and 29 have around 10 buildings per acre in each of the wards which is much higher than the average building density of Khulna city. All these factors are responsible for their moderate vulnerability.

Ward nos. 1, 3, 4, 5, 16, 18, 20, 25, 26, 30 and 31 are found as low fire vulnerable areas. The factors working behind their low fire vulnerabilities are –having road width (around 10 meters) more than average road width of Khulna City (around 8 meters), having more than 50% pucca buildings in respect to their total buildings within their jurisdictions, having far more Lesley dense population (25 persons per acre) than the average population of Khulna city (79 persons per acre) and also having low building density.

For reducing fire vulnerability in high and medium vulnerable wards measures suggested are-widening of roads; land-use zoning; removal of existing poor conditioned buildings; reducing population density; establishment of hospital with adequate facilities for burnt patients and establishment of fire stations; procurement of small firefighting vehicles capable of operating in the areas with narrow roads; procurement of low cost and handy firefighting equipment for pucca and semi-pucca buildings and last but not least, increasing public awareness. Planners and policymakers should focus more on high and moderate vulnerable areas and take urgent steps to reduce fire vulnerability of Khulna city.



Map 2: Spatial Variation of Fire Vulnerability of Khulna City

6. CONCLUSION

This study instigated a process of ward wise fire vulnerability assessment, wielding an Index-based approach for Khulna city, which could provide constructive thought to the planners and policymakers for identifying hotspots so that proper and inclusive management of fire vulnerability of city dwellers could be ensured. Technique and process applied in this paper could be replicated at any similar geographic location. A more detailed analysis could not be placed due to time and resource constraints. Therefore, researchers are suggested to use more variables at neighborhood level for assessing fire vulnerability of Khulna city more comprehensively.

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